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# NATURAL HISTORY

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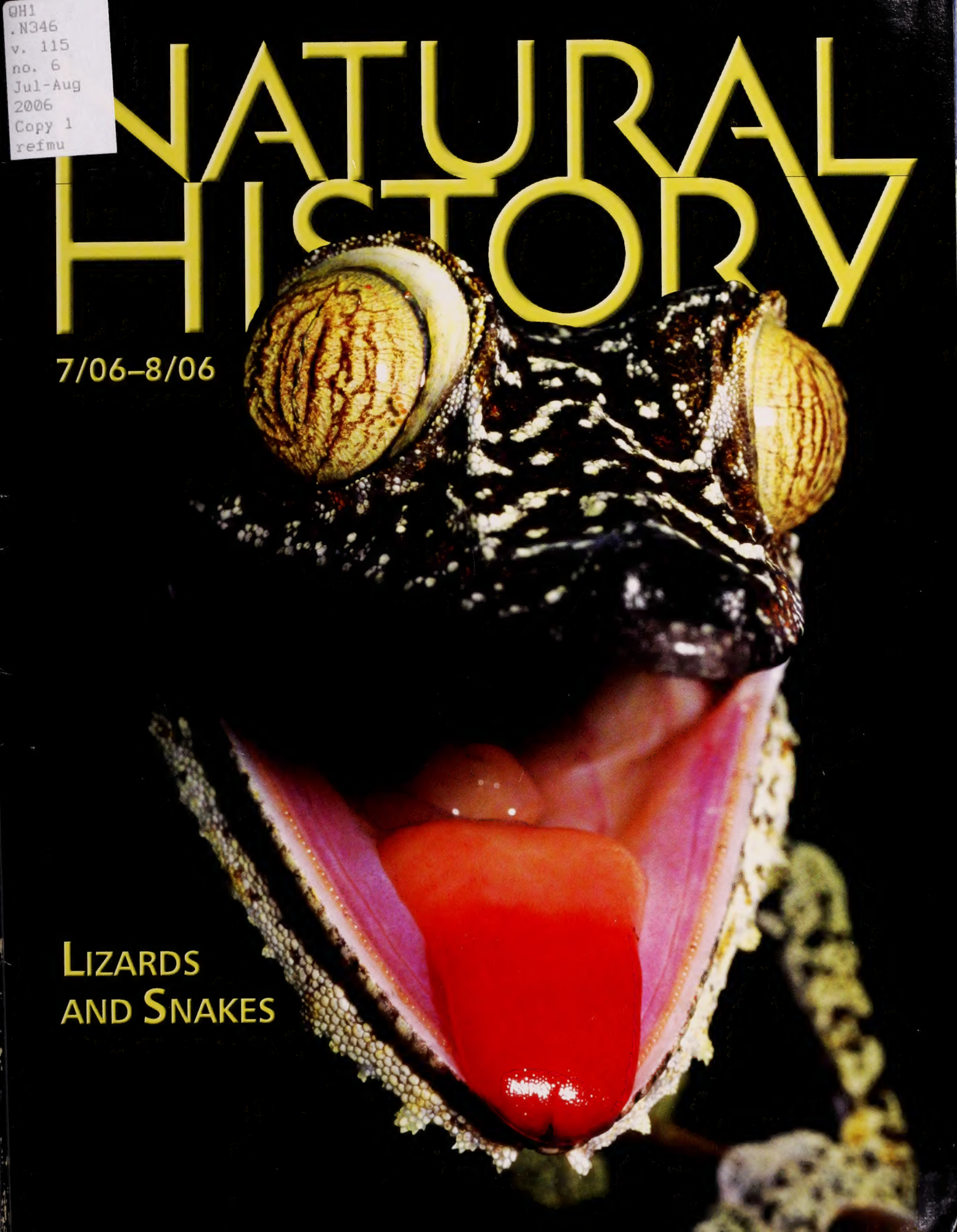

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# NATURAL HISTORY

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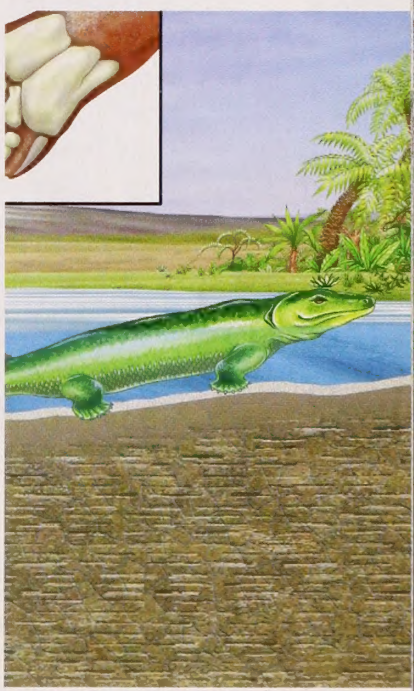

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Defense display of leaf-tailed gecko, Madagascar. Photograph by Claudio Velasquez.

NATURAL HISTORY

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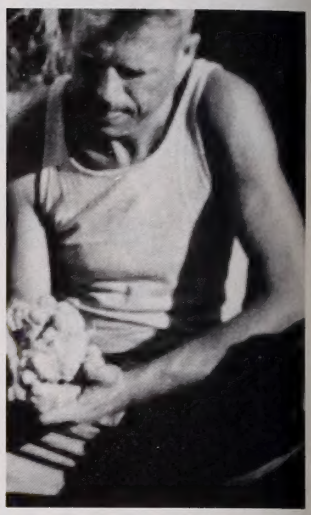

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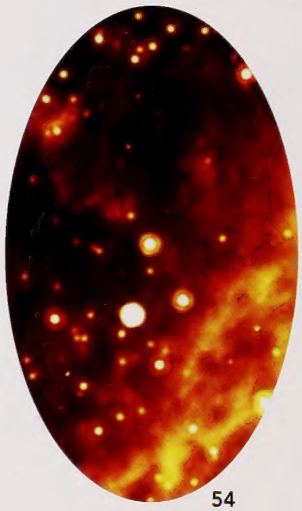

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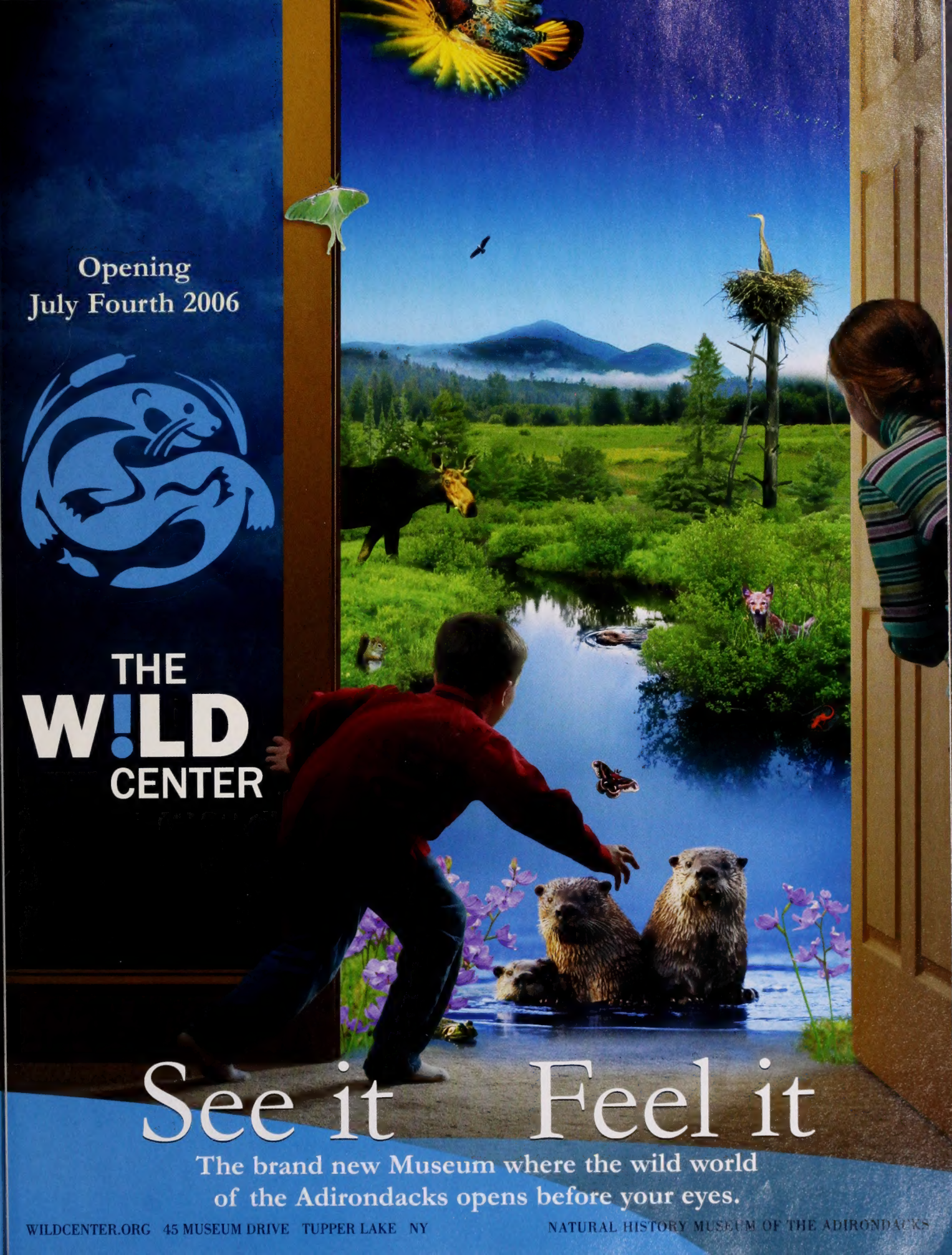
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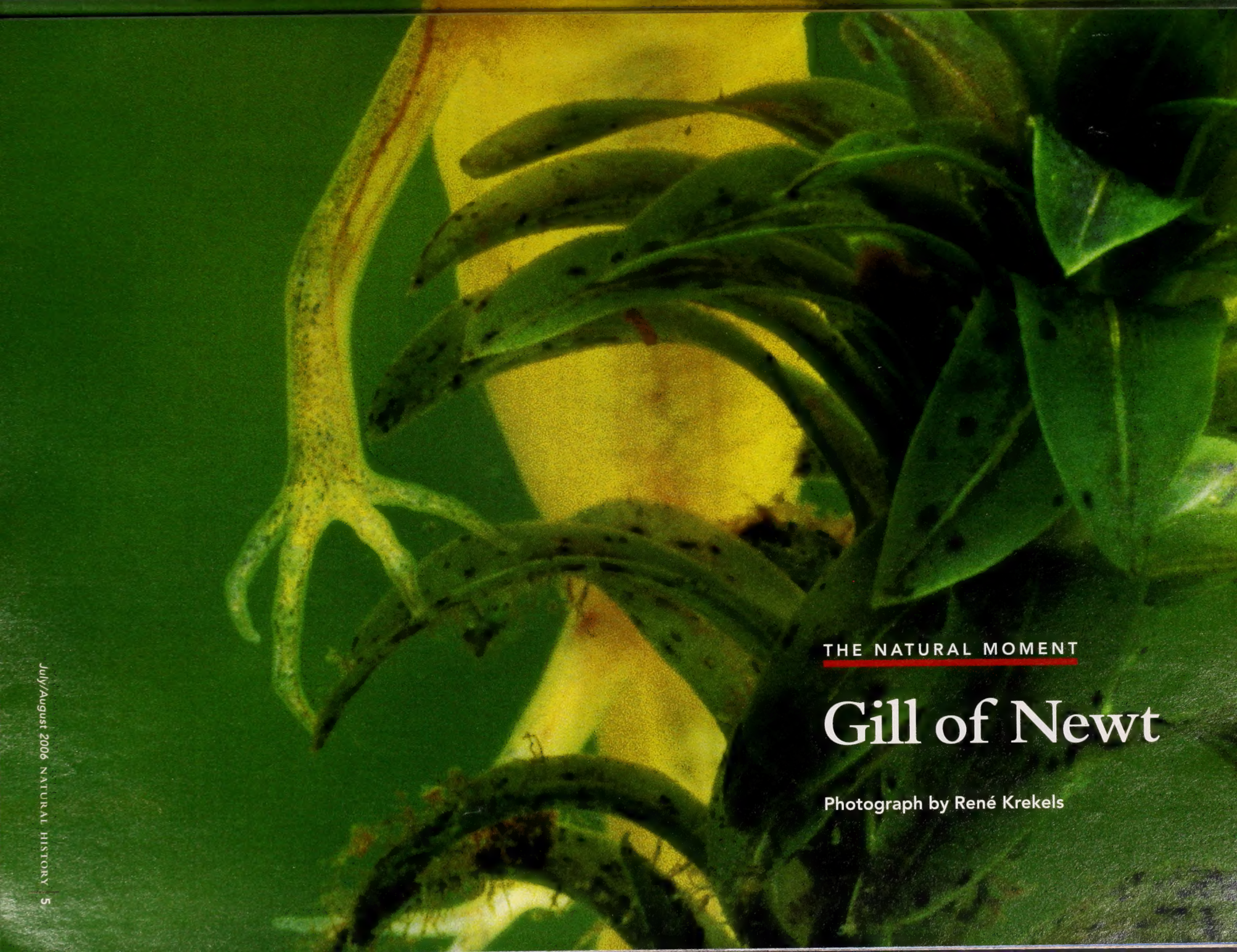

THE NATURAL MOMENT

# Gill of Newt

Photograph by René Krekels

◄ *See preceding two pages*

With all their boiling and toiling, the witches of *Macbeth*—who were cooking with "eye of newt, and toe of frog"—might have been improvising by tossing newt eyes into their cauldron in lieu of a much rarer ingredient: the newt's external gills.

Newts can live for more than twenty years, but they sport feathery gills on their heads or necks only for the first few months of life, in a so-called larval stage. The warty newt *(Triturus cristatus)*, pictured here with its air-catching tiara, probably hatched two or three months before photographer René Krekels saw it. A few weeks later the fishy creature would have absorbed its gills and gone ashore.

Newts don't stay on land forever, though. Sexually mature adults return to the water every spring to mate. A pair doesn't embrace; the male simply drops a sperm packet in the water. If a female deigns to pick it up, she will have one of the longest labors in the animal world. For more than a hundred days the pregnant newt lays two or three eggs a day, meticulously folding them in the tip of a leaf with her hind legs. By July, she's finished laying, and her firstborn of the season are almost ready to join her in leaving the water behind.

Krekels had to take great care in photographing the warty newt—a protected species in Europe. After getting a permit from the Dutch government, he briefly removed a young newt just under four inches long from the southern province of Limberg and photographed it underwater on a familiar plant, *Elodea canadensis*. Four days later, the newt was released—free to stew naturally in its home pond. —*Erin Espelie*



# Back When

The lizard version of the Rolling Stones' legendary stuck-out tongue on our cover is a reminder of just how ancient these creatures are. No, not the Stones. True, the band's tongue logo dates to 1971, primeval by rock 'n' roll standards. But our lizard's direct ancestors go back to the Lower or Middle Triassic, as long as 251 million years ago—and, as a group, Squamata ("the scaly ones," aka lizards and snakes) are just as much with us today as Mick Jagger and Keith Richards. If you, like me, are a big fan of squamates, bliss and rapture are at hand: the new exhibition "Lizards & Snakes: Alive!" opens July 1 at the American Museum of Natural History in New York City, and runs through January 7, 2007. Our cover story, by two of the world's leading experts on squamates, Laurie J. Vitt and Eric R. Pianka ("The Scaly Ones," page 28), makes evolutionary sense out of the extraordinary diversity of lizards and snakes today.

• • •

Run the wayback machine another 130 million years or so, to the Late Devonian, about 380 million years ago. There you reach another milestone in the history of life: the arrival of the first four-legged creatures on land. In the classic version of the event, memorialized in dozens of cartoon images, a fish sprouts legs and crawls out of the ocean onto a deserted beach. But discoveries that made headlines this past April, along with meticulous reconstructions that have enabled paleontologists to identify new evidence in fossils previously labeled "indeterminate," tell a very different story. Jennifer A. Clack, whose work has been at the center of the revolutionary new understanding, fills in the story of twenty-five years of remarkably productive investigations, in her article, "From Fins to Limbs" (page 36).

• • •

Now strap yourself in once more and zoom even further into the past, to the beginning of time, some 14 billion years ago, when our universe began with a big bang. Alex Vilenkin is a leading academic theoretical physicist who heads the Tufts [University] Institute of Cosmology, but the news he brings about the latest consequences of big-bang cosmology ("Beyond the Big Bang," page 42) is anything but stuffy.

According to Vilenkin, "our" big bang is only one of infinitely many others, many of which have given rise to exact duplicates of the world we know. Like raindrops condensing out of water vapor, each big bang is a region of true vacuum—ordinary spacetime—that "condenses" out of a substance called the false vacuum, whose boundaries are expanding furiously. And just as the change from water vapor to liquid water dumps copious quantities of heat into the atmosphere, the change from false to true vacuum releases such prodigious amounts of energy that it generates a big bang. Meanwhile, the rest of the false vacuum continues expanding into a void of its own creation, racing on like an unstoppable wildfire that began from nothing and is now spreading in size by a factor of at least a googol ($10^{100}$) every thirtieth of a microsecond. If your worldview has been shrinking of late, if life's minutiae have been crowding out the big picture, Vilenkin's article is just what you'll need to regain a cosmic perspective.

—PETER BROWN

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## CONTRIBUTORS

**RENé KREKELS** studied biology in the Netherlands before turning to nature photography. Krekels has since concentrated on understanding and photographing small creatures, such as the warty newt in this issue ("The Natural Moment," page 4). He particularly enjoys freeze-framing an insect in flight—a butterfly, a blue-winged grasshopper, a cockshafer—or a frog in mid-dive, with his high-speed camera and a macro lens.

Vitt

Pianka

Both career devotees of lizards and snakes, **LAURIE J. VITT** and **ERIC R. PIANKA** ("The Scaly Ones," page 28) have collaborated in recent years, most notably in co-authoring *Lizards: Windows to the Evolution of Diversity* (University of California Press, 2003), the winner of a number of awards. Vitt is George Lynn Cross Research Professor and Curator of Reptiles at the Sam Noble Oklahoma Museum of Natural History, and a professor of zoology at the University of Oklahoma, both in Norman. He is interested in how the evolutionary history of lizards and snakes has influenced their present-day ecology and behavior. Pianka, who is Denton A. Cooley Centennial Professor of Zoology at the University of Texas at Austin, specializes in the study of monitor lizards. Monitors were the subject of his most recent article for *Natural History* (with Samuel S. Sweet), "The Lizard Kings" (November 2003).

In her study of the evolution of four-legged animals from their fish ancestors, **JENNIFER A. CLACK** ("From Fins to Limbs," page 36) has collected fossils in Greenland, Scotland, and England, and examined specimens from museum collections around the world. Clack earned her Ph.D. in paleontology from the University of Newcastle upon Tyne and joined the University Museum of Zoology in Cambridge as a curator. She is a professor and curator in vertebrate paleontology at the University of Cambridge. Her book about the origin of tetrapods, *Gaining Ground,* was published in 2002.

**ALEX VILENKIN** ("Beyond the Big Bang," page 42) is a theoretical physicist who has conducted research in cosmology for more than twenty-five years. His most recent research has focused on the possible existence of multiple universes and other implications of eternal cosmic inflation, one of the novel ideas he has introduced. His new book, *Many Worlds in One* (Hill and Wang), from which our feature is adapted, chronicles firsthand the birth of a new cosmology that incorporates many of his influential theories. Vilenkin emigrated to the United States from the U.S.S.R. in 1976, receiving his Ph.D. the following year from the State University of New York at Buffalo. He is a professor of physics at Tufts University in Medford, Massachusetts, and serves as director of the Tufts Institute of Cosmology.

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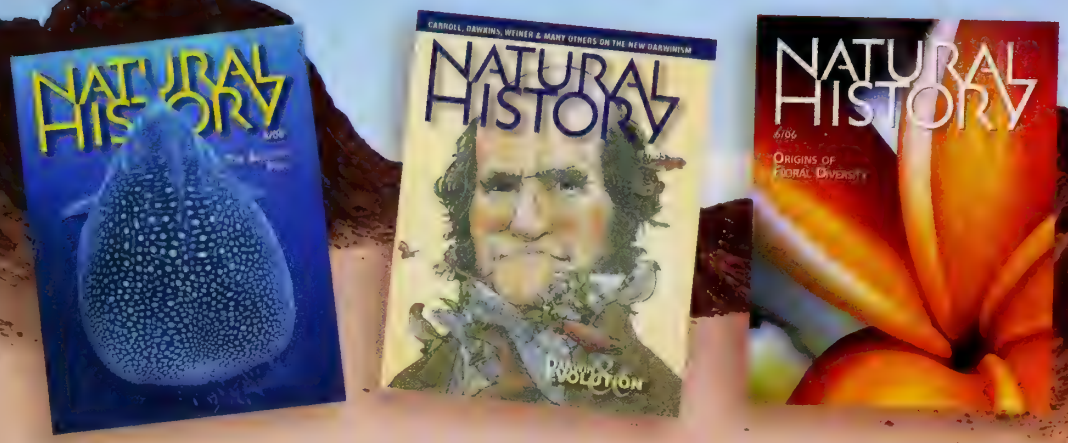


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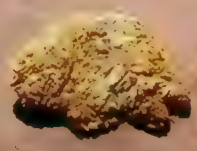


NATURAL HISTORY

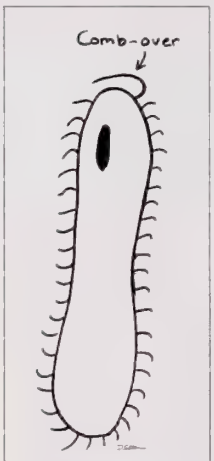
## Coal Wars

Jeff Goodell ["Cooking the Climate with Coal," 05/06] identifies two factors contributing to our increased reliance on coal, namely the self-interest of the coal industry and the denial of global warming. But he fails to note an equally important cause: the single-minded focus of the environmental movement on opposing nuclear power, in the process giving coal what amounts to a pass. That's ironic, because nuclear power, whatever its faults, emits essentially no greenhouse gases.

It's time for environmentalists to rethink their priorities and make stabilizing the global climate job number one.

*John Andrews*
*Sag Harbor, New York*

The objectivity of any article purporting to deal with energy that dismisses nuclear power in one sentence as "uncertain" is open to skepticism. If, as Jeff Goodell's article does, it then goes on to embrace the truly unproven technology of "sequestering" 7 billion tons of $CO_2$ annually (adding 5 billion tons of oxygen to the 2 billion tons of carbon in the coal used by the U.S. and China alone), it is not worth reading.




*Paramecium in midlife crisis*

Nuclear power generates zero $CO_2$ and negligible waste volume, compared with any fossil-fuel technology. A rational environmentalist must favor building new-generation nuclear power plants to replace existing fossil-fuel capacity as rapidly as possible. That's the environmental Manhattan Project that would actually work to reduce the contribution of $CO_2$ to global warming significantly in our lifetimes, and without major economic dislocation.

*Richard B. Mott*
*Ringoes, New Jersey*

Jeff Goodell's thought-provoking commentary still failed to mention the greatest threat of coal-combustion emissions; uncontrolled coal mine fires. According to the *Pittsburgh Post Gazette* (February 15, 2003), uncontrolled coal mine fires in China "make a big, hidden contribution to global warming through the greenhouse effect. Each year they release 360 million tons of carbon dioxide into

*(Continued on page 50)*

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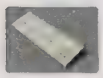

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# Hidden World in the Desert

*Cuatro Ciénegas Basin is an oasis for microorganisms.*

Although the word "oasis" might conjure images of gently swaying palm trees and pools of sparkling water, those rare watery refuges in the desert offer more than just respite for parched travelers. They're also complex ecosystems. According to a recent study, a particularly complex patch called the Cuatro Ciénegas Basin (CCB) lies in the midst of Mexico's windswept Chihuahuan Desert. It covers 325 square miles and includes a diverse array of aquatic habitats, including lakes, marshes, ponds, springs, and streams. Besides hosting more than seventy endemic species of aquatic vertebrates, the CCB shelters a unique community of microorganisms, relics of the oasis's ancient past.

Led by Valeria Souza, an evolutionary ecologist at the National Autonomous University of Mexico in Mexico City, a team of investigators sequenced microbial DNA and discovered thirty-eight previously unknown microbial lineages in the CCB's waters. Surprisingly, the closest relatives of half the lineages are marine species, even though the CCB has been separated from the ocean for tens of millions of years. Souza and her team also discovered closely related microorganisms in valleys outside the CCB—evidence of hydrological connections between the oasis and its surroundings.

In recent years the CCB, a federally designated "area for the protection of flora and fauna," has come under increasing pressure, particularly from the irrigation of nearby alfalfa fields for cattle, which may drain the aquifers that supply the oasis. Souza and her group hope their findings help promote more stringent measures to conserve the region's water. (*PNAS* **103:** 6565–70, 2006) —*Nick W. Atkinson*

# No Laughing Matter

To be top dog in a society of spotted hyenas, you've got to be a real bitch. Fiercely competitive scavengers, hyenas have no truck with the usual mammalian rules of dominance: females control the social hierarchy with an aggressiveness normally exerted only by males. Whether in females or males, aggression means androgens—male sex hormones, such as testosterone—and plenty of them. Biologists have known that prenatal exposure to androgens (independent of an individual's genetic endowment) fosters lifelong reproductive success in birds. Now, Stephanie M. Dloniak and Kay E. Holekamp, wildlife biologists with Michigan State University in East Lansing, and one of their colleagues have shown that prenatal androgen exposure in at least one mammal—the hyena—may translate into access to food and mates.

Androgens, like other hormones, pass from the blood of a pregnant female hyena through the placenta to her developing fetuses. By studying fluctuations in androgen levels during pregnancy, the biologists discovered that during the late stages, dominant females have higher androgen levels than do females further down the pecking order. That extra androgen boost in the womb leads to increased aggressiveness and mounting behavior in cubs of high-status females, traits that should give the cubs a competitive edge later in life.

Practice at mounting is particularly important for male hyenas, say the biologists. The female mates and gives birth through her uniquely masculinized genitalia—an elongated clitoris that resembles a penis. Mating (not to mention birthing) is thus extremely difficult. So, the more mounting males do as cubs, the more successful at mating they're likely to be as adults. (*Nature* **440:**1190–3)

—*N.W.A.*

*Spotted hyena mothers pass down social rank, along with hormones, to their cubs.*

# Oh, the Trials of Motherhood

When it comes to mothering, some caecilians willingly give the skin off their backs. Caecilians are tropical, soil-dwelling, legless amphibians that range in length from four inches to more than four feet. They look like giant earthworms. Alexander Kupfer, a biologist at the Natural History Museum in London, captured and then videotaped twenty-one females of the Kenyan species *Boulengerula taitanus,* along with broods of between two and nine young. Kupfer and his colleagues were amazed to see the young literally munching on Mom.

*Worms? Think again:* Boulengerula taitanus *is an amphibian with strange nursing habits.*

A newly hatched *B. taitanus* has teeth specially suited for peeling off its mother's outer layer of skin—her epidermis. Mom doesn't mind; in fact, she's a willing participant. While nursing, her epidermis grows to twice its normal thickness and develops modified cells full of nutritious fats and proteins.

This newly recognized form of parental care joins a long list of ways parents give of their own bodies to feed their young. Female mammals, of course, secrete milk. Some female frogs and fishes produce unfertilized eggs for their hungry young to eat. But males, too, can be generous: flamingos, emperor penguins, and pigeons of both genders produce "bird milk"—cells that slough off the internal lining of the crop or esophagus—and certain cichlid fishes, male as well as female, secrete nutritious mucus through their skin. (*Nature* **440:**926–9, 2006)

—*Stéphan Reebs*

*Red-bellied black snake and cane toad*

## Beware the Toxic Toad!

Evolution has a way of fighting back. Nowhere is that process more visible than in Australia, where one species of snake is mounting a defense against the cane toad, an ever-encroaching menace. The toad, which can weigh three pounds, was introduced in 1935 in an early attempt at biological control of sugar cane's insect pests. Alas, that well-meaning act unleashed an ecological disaster. Cane toads are toxic enough to kill a person. In addition to devouring native insects and small vertebrates, they've been decimating would-be toad predators, including certain lizards, marsupials, and snakes.

Ben L. Phillips and Richard Shine, biologists at the University of Sydney, are studying the impact of cane toads on Australia's native red-bellied black snake (*Pseudechis porphyriacus*). In a series of experiments, Phillips and Shine have shown that certain populations of the snake have evolved not only to avoid the toads, but also to resist their toxins (to a degree). Those characteristics are hardwired into the snake's genome. The longer a snake population has been exposed to cane toads, the more likely its members are to avoid eating the toads, and the greater their resistance to toad toxins.

Does the snake's evolution offer a glimmer of hope for conserving Australia's native species? Perhaps. But Phillips and Shine have also shown that cane toads at the advancing front of an invasion are evolving longer legs, which enable them to disperse ever more quickly. (*Proceedings of the Royal Society* B, doi10.1098/rspb.2006.3479, 2006) —*N.W.A.*

## Proto-Alexandria

Alexander the Great founded the Egyptian city of Alexandria in 331 B.C. Some scholars say the spot had been vacant land, but given its natural harbor and its proximity to the Nile delta, it should have attracted earlier settlers. Indeed, ancient texts suggest the presence of a prior community, called Rhakotis, but there is little archaeological evidence to corroborate those accounts.

To settle the debate, Alain Véron, an environmental chemist at Paul Cézanne University in Aix–en–Provence, France, and four colleagues extracted cores of sediment from Alexandria's old harbor. They determined the age of each layer of sediment by carbon-dating the seashells and corals trapped within it. Then they measured the amount of lead in each layer, because lead is a telltale sign of advanced human activity. Since ancient times, people have used lead for glassmaking, plumbing, shipbuilding, and statue casting—and also polluted their harbors with it.

As expected, the investigators' analysis shows a sharp increase in industry around the time Alexandria was founded, and elevated levels for hundreds of years thereafter. (In fact, the lead levels in Alexandria's ancient harbor were twice what they are in modern industrial estuaries.) But the analysis also shows two small, earlier spikes. The first dates to about 2300 B.C., when many settlements sprang up in the Nile delta. The second took place about 900 B.C., at the end of the prosperous twentieth Egyptian dynasty, just before Assyrians, Nubians, and Persians got into the habit of invading Egypt and sacking its towns. Rhakotis may not have been much to look at by the time Alexander arrived, but it nonetheless appears to have had a long history of settlement. (*Geophysical Research Letters* **33**:L06409, 2006) —*S.R.*

*Alexandria, Egypt, depicted in a sixteenth-century German map*

## Fog Lifts on Ozone

Way up in the stratosphere—about ten to thirty miles above Earth—ozone protects our planet from damaging ultraviolet radiation. In the troposphere, though—below about ten miles—that same molecule is a potent greenhouse gas. Its exact effect on global warming has remained elusive, but a new study paints the clearest picture yet of how ozone ($O_3$) has affected Earth's climate during the past century.

Tropospheric $O_3$ forms mainly from reactions among certain emissions from fossil-fuel combustion, sunlight, and water. With the help of computer simulations, a team of climate scientists led by Drew Shindell of NASA's Goddard Institute for Space Studies in New York City found that tropospheric $O_3$ levels rose by about 40 percent between 1890 and 1990, but not in a uniform way.

Levels of $O_3$ rose gradually before the 1950s but more quickly thereafter, thanks to surging industrialization across the developed world. Higher $O_3$ levels prevail in regions surrounding industrial centers and in areas prone to forest fires, where substantial quantities of its precursor chemicals are released. Consequently, there's more surface warming in those regions. Increased tropospheric ozone, Shindell's team discovered, thus led to a greater rise in temperatures in the more industrialized Northern Hemisphere than in the less industrialized tropics, and a greater rise in the tropics than in the Southern Hemisphere. And watch out, Arctic ice: $O_3$ is an exceptionally powerful warming agent over reflective surfaces. (*Journal of Geophysical Research* **111**: D08302, 2006) —*N.W.A.*

# Soap in Your Vegetables?

Worried about germs? To calm your fears, modern corporations have added antimicrobial compounds to many household products, including cosmetics, soaps, and toothpastes. One such compound is triclocarban (TCC). About a million pounds of it are manufactured each year in the United States, and at high doses, it's toxic to people. Once used, the compound gets flushed down your plumbing. Where does it go from there?

To understand the fate of TCC, Jochen Heidler, Amir Sapkota, and Rolf U. Halden, environmental health scientists at Johns Hopkins University in Baltimore, monitored the chemical's journey through a large wastewater treatment plant in the eastern U.S. They've got both good news and bad news to tell.

The good news is that the plant removed 97 percent of the TCC from the wastewater it received, and released only 3 percent directly into local bodies of water. The bad news is that the TCC removed from the water gets trapped in the plant's reservoirs of sludge, where it seems impervious to degradation by bacteria. All told, the chemists detected in the sludge about 76 percent of the TCC that had originally entered the plant. That could be problematic: sludge is often recycled as fertilizer, and that could lead to the accumulation of TCC in agricultural fields. From there, the antimicrobial might enter the food supply. TCC in the environment might also give rise to antibiotic-resistant bacteria.

The same team recently developed a test for environmental traces of TCC, then sampled waters upstream and downstream of nine wastewater treatment plants across the country. All of the downstream and more than half of the upstream bodies of water showed traces of the chemical. But it's still not clear whether the stuff accumulates and eventually reaches harmful levels in nature. (*Environmental Science & Technology*, doi:10.1021/es052245n, 2006; *Environmental Research*, in press, 2006) —*S.R.*

# Death Zone

*Cutthroat eels swarm near their deep-sea volcanic abode.*

In a remote tract of the southwest Pacific, thirty miles east of the easternmost island in the Samoan archipelago, a volcanic seamount rises nearly 15,000 feet from the ocean floor, higher than Mt. Shasta in California. At the center of the seamount is a cavernous crater, from which, in just the past four years, a towering, thousand-foot-high cone of hardened lava has emerged.

The crater floor is a death zone, according to Hubert Staudigel, a marine geographer at the Scripps Institution of Oceanography in La Jolla, California, and his colleagues. Recently they've been visiting the seamount, 3,300 feet below the ocean's surface, and have observed numerous carcasses of crustaceans, fish, and squid on the crater floor. The investigators think that strong currents circulating around the seamount wash hapless midwater creatures into the crater's depths; once there, the animals perish because of toxic emissions from hydrothermal vents.

But one creature's hell can be another's paradise. Bright red sea worms inhabit the crater, feeding on the bacteria that thrive on the rotting remains. Near the cone's summit lives an army of cutthroat eels, *Dysommina rugosa*, a species previously known only from trawled specimens. The eels gorge on shrimp carried in by the same currents that occasionally wash some of their comrades into the toxic trap below. (*PNAS* **103**:6448–53, 2006)

—*S.R.*

*Keas: nosy by nature*

# Avian Einsteins

To test the intelligence of birds, ethologists often present them with a piece of food dangling from the end of a string. To get the food, a bird perched on a branch must reach down, grab the uppermost segment of string in its beak, pull the string up, pin it between foot and branch, reach down, grab the next segment, pull that up, and so on. Devilish variations of the test include forcing the birds to choose between two strings, which may be crossed or pulled to one side by wire. For the past decade, the champion string-pullers have been ravens. But recently, keas have taken over the lead.

Keas are inquisitive, olive-green parrots that live in the mountains of New Zealand. (They occasionally strip windshield wipers off cars, seemingly just for the fun of it.) Seven keas reside in captivity at the Konrad Lorenz Institute for Ethology in Vienna. This septet never saw a string in their lives until Dagmar Werdenich and Ludwig Huber of the University of Vienna submitted them to the string-pulling task. Yet the keas figured out the problem in a matter of seconds on their very first try, faster than ravens ever have. Only one fledgling, which was still developing its beak-foot coordination, failed the test.

In birds, feats of intelligence often occur in species that use tools or cache food, as ravens do. Keas, however, do neither. But they're gregarious, and intelligence seems to be useful to animals that operate within social networks. Known as the "social function of intellect," that hypothesis has so far been applied mainly to primates. Could it also be valid for birds? (*Animal Behaviour* **71**:855–63, 2006) —*S.R.*

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# Traveling Green

*Tourists who want to vote with their pocketbooks for sustainable practices can consult networks that certify ecotourist operators. But who certifies the certifiers?*

By Carol Goodstein

The palm-lined shores of Bocas del Toro—a group of small islands on the Caribbean side of northwest Panama—attract a bountiful assortment of species. The waters are resplendent with hundreds of tropical fish, colorful sea stars, spiny lobsters, and massive coral formations. Four species of sea turtles, all endangered, come ashore every year to nest, laboriously pulling themselves onto the beaches. Also here, on the sandy grounds, is the species that sets itself apart: the human, both visitor and inhabitant.

Ten years ago few foreign visitors knew anything about the abundant life-forms on and around these beaches. Then, word of mouth and a booming ecotourism industry that is transforming Latin America brought thousands of tourists to Bocas del Toro. The tourists come to see the sea turtles nesting, snorkel among the blooming coral reefs, and meet the locals. Yet, if the very presence of tourists starts to disrupt the fragile ecosystem they came to see, everyone—native inhabitants, tourists, wildlife, the environmental movement as a whole—loses.

One native of Bocas del Toro, a man named Milford Peynado, was well acquainted with those concerns five years ago when he began to build some simple hotel rooms next to his house on Carenero Island. The rooms he built are not far from a group of rustic fishermen's homes and a smattering of other hotels and restaurants along a narrow beach. For years Peynado relied on fishing for his livelihood. But a steady decline in crab, lobster, and octopus populations forced him and a number of other islanders to look for alternative incomes. A welcome influx of tourist dollars brought wealth to the community, but resident entrepreneurs were still wary of protecting their slice of island paradise.

So Peynado and fellow residents banded together to stave off what could become the high price of popularity. The idea was that sustainable tourism could benefit all of Bocas del Toro's inhabitants, including the migrant sea turtles, but only if it was approached as a long-term commitment—that is, only if it was designed to be sustainable.

Tourism ranks among the world's largest and fastest-growing industries. According to the UN World Tourism Organization (UNWTO)—which serves as a global forum for policy issues affecting tourism—more than 800 million people travel internationally and domestically each year. Some observers predict that tourist arrivals will grow by 4 percent or more a year in the next two decades. Such growth could bring the total close to a billion travelers by 2010.

Unregulated, all that globetrotting can overwhelm the resources at natural sites; uncontrolled ecotourism may displace local people, threaten wildlife by introducing non-native species, and pollute the area. Moreover, evidence suggests that tourists are being drawn in increasing numbers to the hotspots of biodiversity—the very places that need protection the most.

Yet tourism can also be a powerful conservation tool. Conservation and wildlife protection often require direct financing, which can be extraordinarily expensive. In Rwanda, for instance, which is still recovering from years of genocide, tourism has helped protect the mountain gorilla population and its habitat. Tourists visiting Parc National des Volcans, about a ninety-minute drive from Kigali, pay $375 each to accompany a local guide who can track lowland gorillas for a day. The national park generates $1 million annually for the Rwandan government, which is used to support the management and operation of the country's protected areas. For the Galápagos Islands, tourism generates as much as $38 million a year. Belize levies a conservation tax of $3.75 on every foreign visitor who leaves the country, generating about $750,000 a year. A percentage of that money, too, goes into a national trust and back into the country's natural areas.

Of course, compared with the capitals of world tourism—think of Italy or Greece—those are paltry receipts. Yet it would be a mistake to conclude that for countries such as Belize, Ecuador, or Rwanda tourism is unim-

portant. In fact, tourism is a primary source of foreign-exchange income. Moreover, the potential for the growth of ecotourism in those countries is enormous, albeit still unrealized. Those points only highlight the need for the countries to promote "traveling green." A recent survey by an online travel agency in the United Kingdom known as responsibletravel.com found that 80 percent of tourists would be more likely to book with a tour operator that has a so-called green policy in place. People who want to travel to pristine locations do not want to be responsible for causing damage, and they often seek out tourism operators that advertise "environmental awareness." Yet what controls are in place for would-be travelers and responsible business owners to verify claims that sustainable tourism is in place?

In 1992 a UN conference on the environment, the so-called Earth Summit, was held in Rio de Janeiro. The conference spawned a pact known as Agenda 21, which called for sustainable development and in turn led to a profusion of new certification systems. The vast disparity that grew up among those systems eventually prompted the organization I am associated with, the Rainforest Alliance, to study whether universal standards could be set for sustainable tourism. We are now working with the International Ecotourism Society to build a global network that promotes higher standards of tourism.

Programs that certify sustainable practices often work much like the "star" ratings, which companies such as Michelin or Mobil award when they publish their travel guides to hotels and restaurants. They can be subjective or rigorous, expansive or narrow. In the more reputable programs, second- or third-party assessors inspect business establishments that hope to be certified. Their seals of approval are granted only temporarily and must be re-earned every few years, as technology, the environment, and tourist traffic evolves.

Hence the very process of certification acts not only as a tool for measuring and enforcing compliance with pre-established criteria, but also for promoting them. Travel surveys and plain economic demand demonstrate that tourism businesses have an economic interest in being listed as green. So long as the certification process itself is incorruptible, certification offers the incentive for substantial economic reward to businesses for good behavior. By setting up appropriate certification criteria, some of the certification programs—which go by such names as Blue Flag, Green Deal, and Green Globe—are making their own concerted efforts to control unchecked development and foster responsibility among so-called eco-establishments [*see sidebar on this page for a few examples*].

| | COVERAGE | EXAMPLES OF CERTIFICATION CRITERIA OR PROTOCOLS |
|---|---|---|
| BLUE FLAG | *Beaches and marinas in Canada, the Caribbean, Europe, and parts of Africa* www.blueflag.org | *Sites must have an emergency plan in place for pollution accidents, and be available for unannounced water-quality inspections.* |
| eco CERTIFIED Tourism | *Accommodations, tours, and attractions in Australia* www.ecotourism.org.au | *Third parties often do onsite, random audits; certification must be renewed every three years.* |
| Green Deal | *Tour operators, hotels, and restaurants in Guatemala* www.greendeal.org | *A team of independent auditors looks at environmental practices and cultural relations.* |
| GREEN GLOBE | *Tour operators, restaurants, resorts, and more, around the world* www.greenglobe.org | *Starts with "benchmark" standards that must be met before full certification (signaled by a checkmark through the globe icon).* |
| The Green Key | *Accommodations in Denmark, Estonia, France, Greenland, and Sweden* www.green-key.org | *Inspects energy consumption and chemical use; sets individualized goals for each site.* |

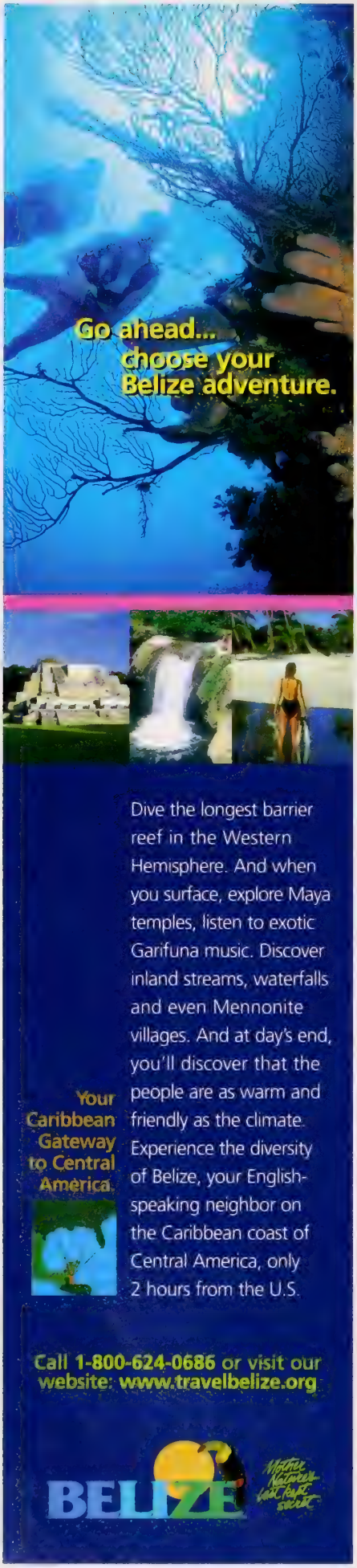
*Ecotourist organizations around the world—such as the ones symbolized by the logos above—feature a bewildering variety of certification criteria and protocols to ensure compliance. Some are banding together to standardize the meaning of "green."*

One criterion common to most meaningful certification programs concerns the use of water. Big resorts consume as much as 300 gallons of water per guest per day. Any hotel that can cut that consumption takes a major step toward a sustainable enterprise. Stanley Selengut, who has operated a Maho Bay resort on Saint John in the U.S. Virgin Islands since 1974, has installed low-flush toilets, pull-chain showers, and low-flow faucets; his average has tumbled to twenty-five gallons of water per guest per day.

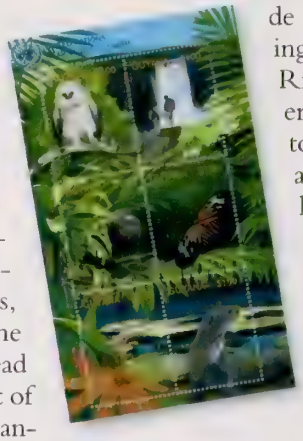
One benefit of the focus on sustainability, Selengut says, is that each step in that direction "has led us to new opportunities and new innovations with unforeseen applications." He started his hotel with eighteen tentlike cottages on elevated walkways, designed so as not to disturb the local vegetation on the steep hillside or cause damage to the reef just below. No construction roads were created, few trees were removed, footings were dug by hand, and use of heavy machinery was minimized.

Once the resort was operating, Selengut realized he could enhance the environment with its by-products. He began to put "graywater"—wastewater from washing machines and the like that does not need to be chemically treated—compost, and recyclable materials to good use. "Our use of graywater has not only enabled us to cut down on our use of a precious island resource," he says. "But it's also led us to a comprehensive system of site restoration"—including the reintroduction of native plants, natural methods of insect control, and wildlife management.

Although sustainable tourism has been adopted primarily by small, independent operators, a number of the world's larger tourism companies, from hotels to tour operators, are also restructuring their management and operations. The aim is to reduce the consumption of water, energy, and




other resources, and to improve the management of waste. In Jamaica, for instance, dozens of hotels—from small, family-run operations to Sandals, the island's largest hotel chain—are now Green Globe certified.



There is nothing mystical about the process. To get certification from such an organization, hotels can make headway just by eliminating leaks, using water-saving toilets and showers, turning sprinklers on in the morning or evening instead of in the evaporative heat of the day, and avoiding cleaning products that contain bleach. And in meeting those requirements, the hotels are not only able to do good for the environment, but also for the bottom line. Small hotels, which typically spend between $700 and $1,500 to make the needed improvements, usually find that the changes pay for themselves in less than a year.

When Peynado built his hotel in Bocas del Toro, he believed in sustainable tourism, but he wasn't sure how to put it into practice. Last year he and other business owners from his area took part in a conservation training session hosted by the Rainforest Alliance. As of April 2006, more than 2,000 people had attended Alliance workshops throughout Belize, Costa Rica, Ecuador, Guatemala, and Panama. The workshops are held to show the owners how to cut costs and mitigate the negative effects of their hotels on the environment by reducing energy and waste. Alliance workshops also introduce many business owners to sources of funding that can help them meet those goals. For example, participants are encouraged to apply for "green funds" such as Verde Ventures, a $7 million investment fund managed by Conservation International, a nonprofit environmental organization, which offers grants to programs that benefit the conservation of biodiversity.

Ten years ago an American expatriate named Eddie Ryan bought a patch of rainforest along Costa Rica's southern coast near Puerto Viejo. There he built a small hotel called Costa de Papito, and now he is reaping the benefits, because Costa Rica has come to be considered a mecca for sustainable-tourism development. Ryan, a regular at Rainforest Alliance workshops, asked his guests to recycle garbage, turn off lights, and reuse their towels. Many of them return home converted by his missionary zeal. Local neighbors, too, seem to be picking up on the environmental doctrine. And Costa Rica's lead has spread to other Latin American countries and around the world.

Helping consumers choose among the hundreds of certified options remains a challenge. Every certification program seems to have its own set of criteria, and the degree of compliance with them varies widely. Some hotels consider themselves "green" if they put a sign in their guests' bathrooms asking them to reuse the towels. But slowly, in the past few years, a common language, along with minimum standards, has begun to emerge as regional networks have grown up.

The regional approach has developed as people realized that what is needed to make an environmentally sustainable and socially responsible enterprise varies enormously with location. What might work for a business in, say, the Gobi desert, might be totally inappropriate in a Guatemalan rainforest or in the mountains of Bolivia. The most highly developed regional networks are VISIT and ECOTRANS in Europe and the Sustainable Tourism Certification Network of the Americas (STCNA). (The Rainforest Alliance currently serves as the secretariat for STCNA.) Strong, fledgling efforts are also underway in Africa and in the Asia-Pacific region.

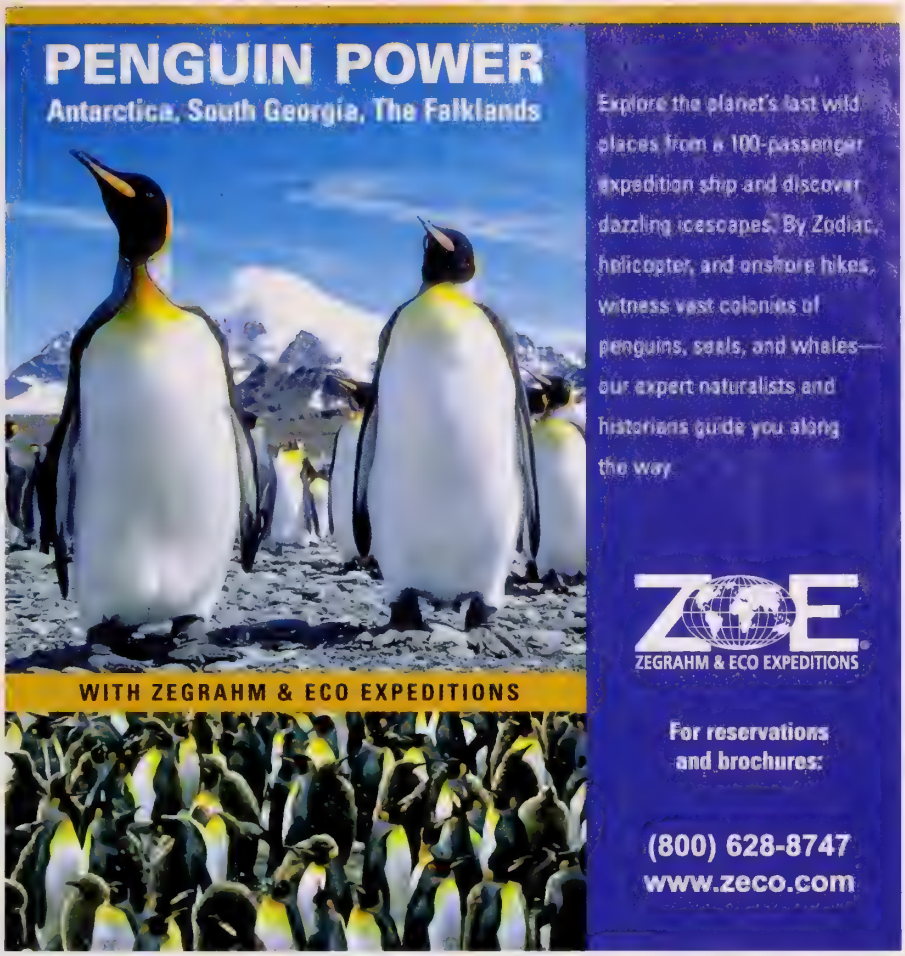
In September 2005 STCNA ratified

a comprehensive set of eighty-eight criteria for sustainability. They aim, in general, at reducing waste, water use, and energy use; protecting the environment; and providing education and economic benefits to local communities. The acceptance of those criteria across the wide STCNA network will be an enormous help to travelers in evaluating hotels, lodges, and other businesses. The network is also establishing an ad hoc committee with representatives from other regions around the globe to standardize the criteria; it is working with ECOTRANS to establish an international comparison of certification requirements that extends beyond the Americas. Those partnerships and networks will enable small hotels such as Peynado's to be noticed and marketed in a large forum.

It has become patently clear that sustainable tourism is a viable and promising conservation tool. But it remains challenging to provide the residents of the world's most remote, fragile, and biodiverse ecosystems with the incentive to invest in the long-term vision of sustainable development—as opposed to the short-term gains of business as usual. Even if eco-establishments have the best intentions, it is by no means straightforward to provide them with the tools, know-how, and capital to accomplish what they need to maintain a sustainable ecosystem.

Yet if Peynado's neighbors and his neighbors' neighbors come to realize the inherent wisdom of sustainable tourism—and more, convey that wisdom to their guests—the benefits promised by sustainable development remain very much within reach. As Peynado puts it, "One of our main assets here is the environment. If that goes, your business goes. So if you can do anything to protect it, you know you'll still be in business."

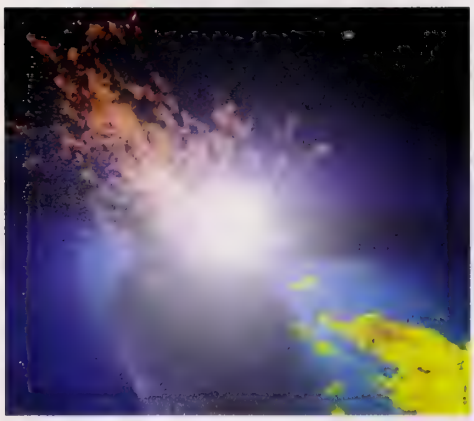
*Carol Goodstein is the senior writer and editor for the Rainforest Alliance. She works to educate consumers on how their purchases can affect lives and lands of people around the world.*

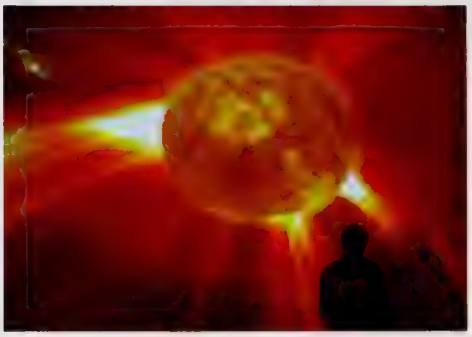
# Art and Science Collide in the American Museum of Natural History's New Space Show

Cosmic Collisions *Offers*
*Rose Center Audiences*
*a Crash Course in Astrophysics*

The spectacular new Space Show in the Hayden Planetarium at the American Museum of Natural History's Rose Center for Earth and Space may feel like science fiction, but it's not. Through cutting-edge computer technology, *Cosmic Collisions,* narrated by award-winning actor, director, and producer Robert Redford, turns raw scientific data into breathtaking 3-D images of cataclysmic events in space.



The production, two years in the making, takes viewers on a thrilling journey past, present, and future to witness such explosive encounters as a Mars-sized object smashing into a young Earth to form our Moon, the impact of the meteorite that doomed the



dinosaurs 65 million years ago, and the projected collision of the Milky Way and Andromeda galaxies in the far-distant future.

More than 100 scientists from around the world contributed their expertise to the project, weighing astronomical observations against predictions based on the laws of physics to arrive at the most accurate renderings possible. The show's depiction of the Milky Way and Andromeda galaxies on a collision course, for example, is based on data-driven computations of how the stars, gas, and dark matter in the galaxies will behave under the influence of gravity and gas pressure over the next 6 billion years. The result is a beautiful intergalactic ballet across the Hayden Planetarium dome, the two galaxies swirling and stretching away from each other and coming back together again in a simulated sequence where each second equals the passage of 40 million years.

In other mathematically meticulous simulations, interspersed with satellite images and accompanied by seat-shaking vibrations, the Show explores the secrets of the Sun, the northern and southern lights, the remote but disturbing possibility of a killer asteroid hitting Earth and what we might do about it, and more. In the end, this engrossing, immersive theater experience proves that seemingly destructive processes are, in fact, constructive, forming galaxies, changing the course of life on Earth, and continuing to transform the universe.

Cosmic Collisions *was developed by the American Museum of Natural History, New York (www.amnh.org), in collaboration with the Denver Museum of Nature & Science, GOTO, Inc., Tokyo, Japan; and the Shanghai Science and Technology Museum.*

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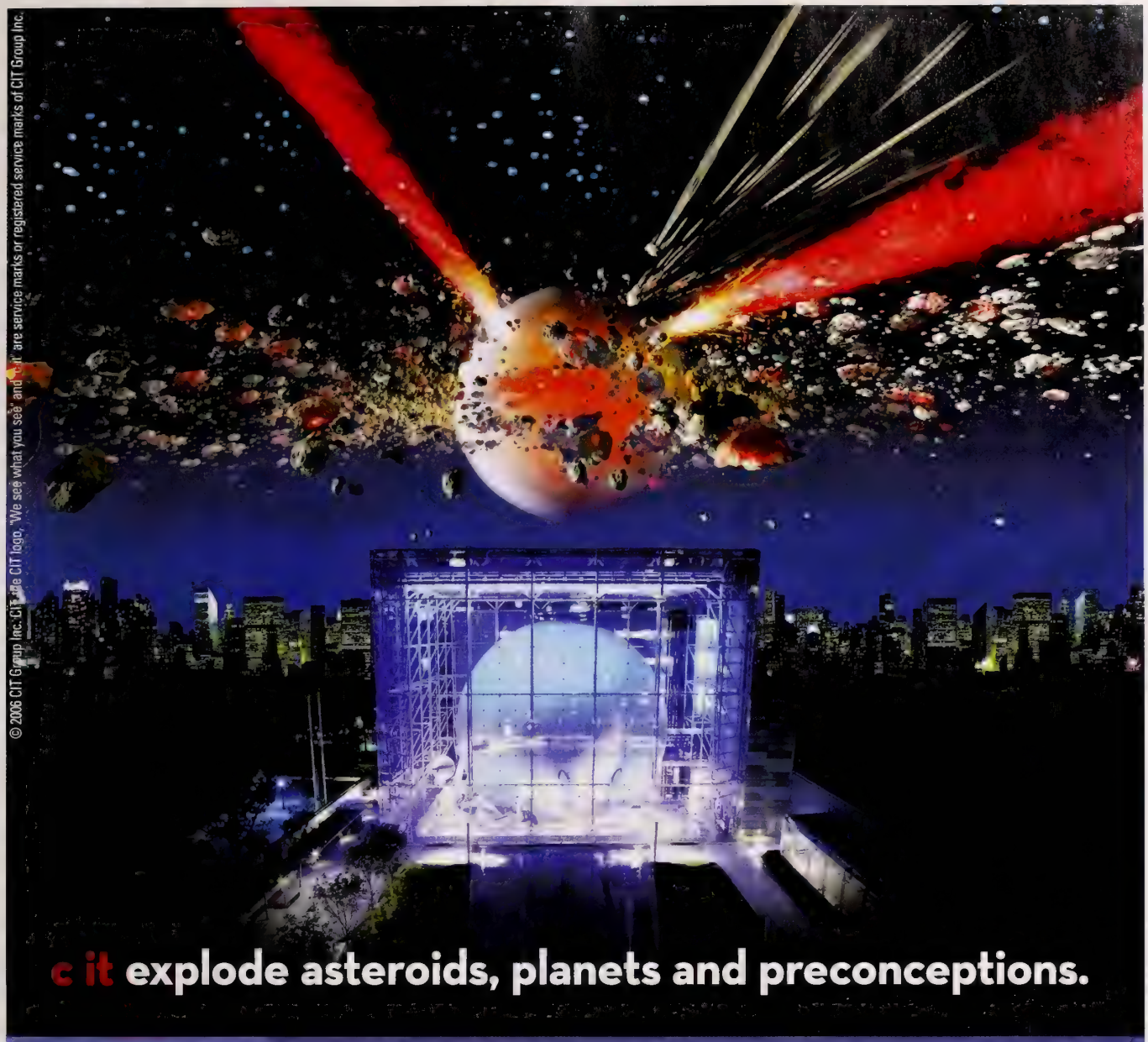

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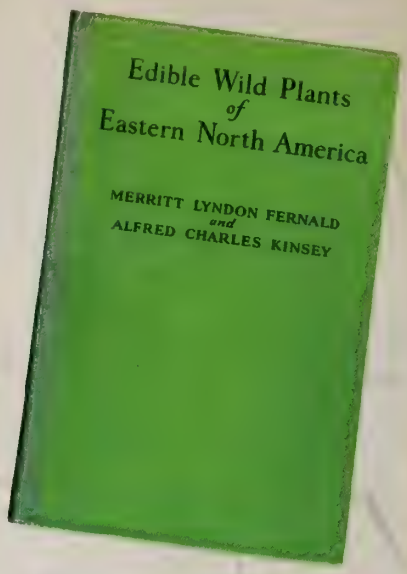
# The Other Kinsey Report

*Alfred C. Kinsey's scientific interests went well beyond sex.*

By Peter Del Tredici




Edible Wild Plants of Eastern North America, *shown above in its original, 1943 edition, was the culmination of Alfred C. Kinsey's little-known passion for botany.*

Alfred C. Kinsey, the sex doctor, died fifty years ago this August. The occasion offers the chance to reconsider a figure whose interests ranged over a great deal more than the varieties of human sexual behavior. Kinsey began his career as an entomologist, but he was also passionate about plants. In fact, he collaborated with Merritt L. Fernald, a prominent professor of botany at Harvard University, to produce the classic *Edible Wild Plants of Eastern North America*. That book, published in 1943, still stands among the best of its kind for the number of species it covers, the accuracy of its descriptions, and the practicality of its recommendations for harvesting and preparing wild foods.

When I purchased my first copy of *Edible Wild Plants* in the early 1970s, at the start of my own botanical career, I had no idea that its author was *the* Alfred Kinsey of the famous Kinsey reports. *Sexual Behavior in the Human Male* (1948) and *Sexual Behavior in the Human Female* (1953), each based on interviews with thousands of Americans, gained notoriety because they depicted a populace more sexually experienced and willing to experiment than the prevailing culture of the time cared to acknowledge. The two books sparked considerable controversy and public debate, made Kinsey a celebrity, established the field of sexology, and have been credited with launching the sexual revolution of the 1960s. But even after I belatedly made the connection between botanical manual and sexual exposé, I never quite figured out how Kinsey, the famous sex doctor, and Fernald, the famous botanist—strange bedfellows if ever there were any—came to be linked through such a seemingly mundane subject as edible plants.

*Merritt Fernald, Kinsey's botanical collaborator, circa 1940*

My question lay dormant for nearly thirty years, until I saw the biographical movie *Kinsey* in December 2004. In the opening scene, Professor Kinsey (played by Liam Neeson) is training his research assistants to record people's sex histories by having the assistants interview him. When an assistant asks about his education, Kinsey replies that he received his doctorate from "the Bussey Institution of Harvard University." The words made me sit straight up in my seat, as the proverbial light bulb turned on in my brain. The Bussey Institution, now defunct, had been Harvard's agricultural college in Jamaica Plain, Massachusetts, adjacent to the Arnold Arboretum where I work. Fernald had been a professor there.

Within a week of seeing *Kinsey*, I e-mailed the archivist at Harvard's Gray Herbarium to see whether there were any files on Kinsey related to *Edible Wild Plants*. The response came back positive: the archives held two folders of letters between Fernald and Kinsey, plus some manuscript pages for the book. I made an appointment to look over the files the following week, and I bought Jonathan Gathorne-Hardy's biography of Kinsey to find out what was already known about the history of *Edible Wild Plants*. Next to nothing, it turns out. That biography and others mention the book only in passing.

Kinsey was born in Hoboken, New Jersey, on June 23, 1894. A sickly child, he had a tumultuous relationship with his father, who was sternly religious. Kinsey developed a deep love for the outdoors and found solace from his difficulties in the study of the natural world. His interest in nature led him to join the Boy Scouts and, at age eighteen, he became one of the first Americans to attain the rank of Eagle Scout. He was particularly intrigued by

the varied art of woodcraft, the skill of living off the land, and spent most of his summers until age twenty-seven as a camp counselor in various parts of northern New England.

In 1916 Kinsey graduated from Bowdoin College in Brunswick, Maine, with a degree in biology. That September he enrolled in the doctoral program in economic entomology at the Bussey Institution. Fernald, a member of the Harvard faculty, taught a botany course at the Bussey. He had established his reputation by coauthoring the seventh edition of Asa Gray's famous *Manual of Botany,* published in 1908, and would later serve as director of the Gray Herbarium. It's not clear how Kinsey and Fernald met, but the Bussey was a small institution and the paths of the two men, who shared a common interest in plants, undoubtedly crossed early in Kinsey's tenure there.

*Kinsey examines galls—woody structures that gall wasps induce oak trees to produce—in this 1935 photograph.*

For his doctoral research, as movie fans will recall, Kinsey chose to work on gall wasps. The insects induce oak trees to produce bizarrely shaped woody growths to harbor developing gall-wasp eggs. By September 1919, doctorate in hand, he embarked on a year-long field trip to collect gall wasps. He traveled across much of the southern and western United States, on public transportation and on foot, camping and living off the land whenever possible. His travels ended by August 1920, when he joined the zoology department at Indiana University in Bloomington as an assistant professor of entomology. There, Kinsey continued working on gall wasps, collecting and classifying hundreds of species and becoming an authority on their evolution, until he began his studies on human sexuality in the late 1930s. By that time, he had collected more than five million galls and gall wasps, now housed at the American Museum of Natural History in New York.

Kinsey's plan to write a book on edible wild plants took root when he was still a student at the Bussey. Somehow, while taking courses, working on his dissertation, and teaching undergraduate courses in zoology, he found time to compose a rough draft of *Edible Wild Plants.* In short, Kinsey's passion for botany was as strong as it was for gall wasps or, indeed, in later years, for sex. In any event, at some time before he graduated from Harvard, Kinsey enlisted Fernald as a coauthor of the book, undoubtedly to help flesh out its technical plant treatments.

When I sat down at a long table in the library of the Gray Herbarium and began leafing through the sixty-four surviving manuscript pages of *Edible Wild Plants,* I was most struck by their physical appearance. Kinsey wrote the manuscript on a combination of now-crumbling newsprint and used sheets of herbarium card stock that had bits of old labels stuck to them. The pages are large—fourteen by twenty-two inches—and written on both sides in Kinsey's distinctive, loopy hand [*an enlarged example appears in the background on this and opposite pages*]. A manuscript written on recycled paper is vintage Kinsey; even after he became famous for his sex research, he was notorious for his frugality. No doubt his interest in edible wild plants—read "free food"—was part of his belief in the intrinsic moral value of thriftiness.

The surviving manuscript pages include an introduction, a classification of edible wild plants into fourteen categories of uses, and descriptions of some thirty poisonous plants that could be mistaken for edible ones. Remarkably, almost all of his writing has been preserved intact in the introduction and the first seventy pages of the published book. The classification into various usage categories—including such idiosyncratic groupings as "Nibbles and Relishes," "Rennets," and "Masticatories and Chewing Gums"—is an early manifestation of Kinsey's lifelong fascination with taxonomy. All his research interests reflect that urge to classify. Even more striking is the evidence of Kinsey's attraction to primitivism, an inclination that shines through in the first two sentences of the book:

> "Nearly every one has a certain amount of the pagan or gypsy in his nature and occasionally finds satisfaction in living for a time as a primitive man. Among the primitive instincts are the fondness for experimenting with unfamiliar foods, and the desire to be independent of the conventional sources of supply."

The statement illuminates the philosophical basis of Kinsey's interest in wild plants. And its emphasis on experimentation, primitive instinct, and independence from social norms seems

to foreshadow his interest in the nature of human sexuality.

Unfortunately, no manuscript pages survive for the great bulk of the book. The latter includes detailed descriptions and discussions of the edibility of more than a thousand species of plants, mushrooms, seaweeds, and lichens. It is thus impossible to determine precisely who—Kinsey or Fernald—wrote which parts of the book. The handwritten manuscript pages make it crystal clear, however, that Kinsey developed the book's format, established its tone, and wrote the first draft. Fernald added numerous species, brought the nomenclature and technical descriptions up to date, and commissioned the book's 149 illustrations.

In reading through Kinsey and Fernald's correspondence, the earliest reference I found to *Edible Wild Plants* was in a note Kinsey wrote to Fernald on December 12, 1919, from Alamogordo, New Mexico, in the midst of Kinsey's cross-country gall-wasp-hunting trip: "Hope the fate of the book is coming out all right." When he left Boston, Kinsey had apparently entrusted Fernald with the task of preparing the manuscript for publication.

The next mention of the project comes about ten months later, on October 5, 1920. In a letter to Fernald from his new home in Bloomington, Indiana, Kinsey inquired after the book and offered to resume work on it now that he had settled down. Fernald replied with the unfortunate news that the book had been rejected by a prospective publisher. Kinsey took the news philosophically, "I am, of course, very sorry to hear that the publishers cannot handle the book at this time. I shall hope that a favorable opportunity for getting the thing out will turn up before too long a time."

In spite of their failure, though, the two men continued to exchange letters through 1926. In one of them, Kinsey suggested changing the manuscript entry for the American persimmon: "Since coming into a region where the persimmon is abundant as a native, I have intended writing you that we must surely change our remarks on this fruit. I am willing to go more miles to gather persimmons than any other wild food product that I know of." He concluded the letter with the following note:

> Every year since we have been married, Mrs. Kinsey has served persimmon pudding in our house two or three times every week from the first of September until December. We venture to serve persimmon pudding whenever we have guests in the fall, and up to date have never found one who did not consider it a very great treat.

A complimentary entry on the persimmon and Clara B.M. Kinsey's recipe are included in the published book [*see recipe above*].

## Clara B.M. Kinsey's Persimmon Pudding

| | |
|---|---|
| 2 cups persimmon pulp | 1 teaspoon soda |
| 1 cup (scant) sugar | 1/2 teaspoon salt |
| 1 egg | 1 teaspoon cinnamon |
| 2 cups milk | 1/2 teaspoon cloves |
| 2 cups flour | 1/2 teaspoon allspice |

Combine the ingredients, beating well. It is best to save about half the milk until all the flour has been added. Pour about 1 1/2 inches deep in well greased pans and bake about an hour in a 325° oven. The pudding turns dark brown when it is done. Serve either warm or cold with whipped cream. Soft, juicy persimmons make the best pudding.

The correspondence between Kinsey and Fernald slowed dramatically after 1926. No mention of "the book" is made until January 7, 1943, when Fernald wrote excitedly to Kinsey:

> That long-buried manuscript on the *Edible Wild Plants* has suddenly come to life. You may remember that 25 years ago I tried to get it published, but four different publishers after accepting it, sent it back because they saw no way to cover the expense of the illustrations and thought that the market was too limited. Now it seems desirable to get the manuscript up-to-date, which I am doing, and the Idlewild Press of Cornwall, N.Y., has offered to print it in their best style (which is rather nifty).

Kinsey responded positively to this "pleasant surprise," then went on to add:

> However, since my name is going to be on this thing, and since I have some scientific reputation on the basis of my other work, I wonder if it would not be desirable to have me read the manuscript again before it goes into print.

By "other work," Kinsey was referring to his sex research, which he had begun in 1938 and was now thoroughly absorbed in pursuing. Fernald had greatly expanded and embellished the manuscript, which now bore little resemblance to the original draft of 1919. Yet Kinsey, ever the perfectionist, went on to submit some five pages of detailed edits to the manuscript.

It is probably no coincidence that *Edible Wild Plants,* after lying dormant for so long, was published when it was. Kinsey had recently secured a grant from the National Research Council and the Rockefeller Foundation for his sex research. Ernest G. Stillman, an official at the book publisher, Idlewild Press, was also a graduate and benefactor of Harvard University, and a member of a prominent banking family. The well-connected Stillman would almost certainly have been aware of Kinsey's "other work" and its prominent funders. And Stillman was surely mindful of the publicity value of having Kinsey's name on the book's cover, just when his sex research was gaining prominence.

The book finally came off the presses in 1943. To the surprise of almost everyone involved, it was successful enough to warrant a second printing that same year. One reason was that the

U.S. Army, then in the throes of the Second World War, used the book in its wilderness-survival training program. The book's publication also coincided with food shortages then sweeping the nation. As Fernald pointed out in his revision of Kinsey's introduction, the consumer of edible wild plants "will be most content; and every time he will recognize that he has made small draft on the ration-book of coupons."

In 1947 Kinsey established the Institute for Sex Research, Inc. (now the Kinsey Institute for Research in Sex, Gender, and Reproduction, Inc.) at Indiana University. The first of his explosive reports was published in 1948, establishing his legacy. Fernald died in 1950, shortly after finishing the eighth edition of Gray's *Manual of Botany.* Soon thereafter, Reed C. Rollins was appointed director of Harvard's Gray Herbarium, and he wrote Kinsey to propose a revised edition of *Edible Wild Plants.* Kinsey agreed, but the publication of the second edition, like that of the first, suffered long delays. In fact, Kinsey died on August 25, 1956, of congestive heart failure, before the second edition came out. Not until 1958 did Harper & Row publish the second edition, which remained in print through the mid-1970s. *Edible Wild Plants* was reprinted in 1996 by Dover Publications, and it is once again widely available at an affordable price.

Who could have guessed that a manuscript on edible plants, written on used herbarium sheets by a frugal graduate student in entomology, would become one of the classics in its field, entertaining and educating readers even eighty-seven years later? Its existence is testament to an enduring collaboration by two authoritative scientists, and to Kinsey's extraordinary intellectual flexibility and scientific curiosity. Just don't leaf through it and expect to find any sex.

*PETER DEL TREDICI is senior research scientist at the Arnold Arboretum of Harvard University, where he has worked since 1979. He is also a lecturer at the Harvard Graduate School of Design, where he teaches courses on plants, soils, and urban ecology.*

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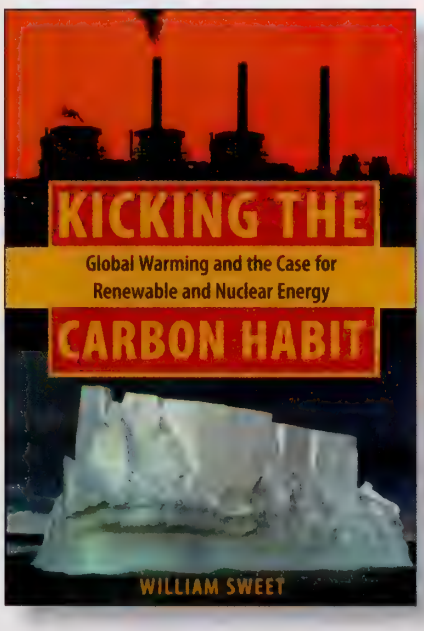


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BIOMECHANICS

# Keep Me Hanging On

*Surviving in the intertidal zone tests the rubbery limits of algae.*

By Adam Summers ~ Illustrations by Tom Moore

Now is a lovely time of year to head down to the beach. But forgo the warm sand in favor of the more interesting rocky headland down the shore. Then, as the waves pound in, consider what it must be like to live here.

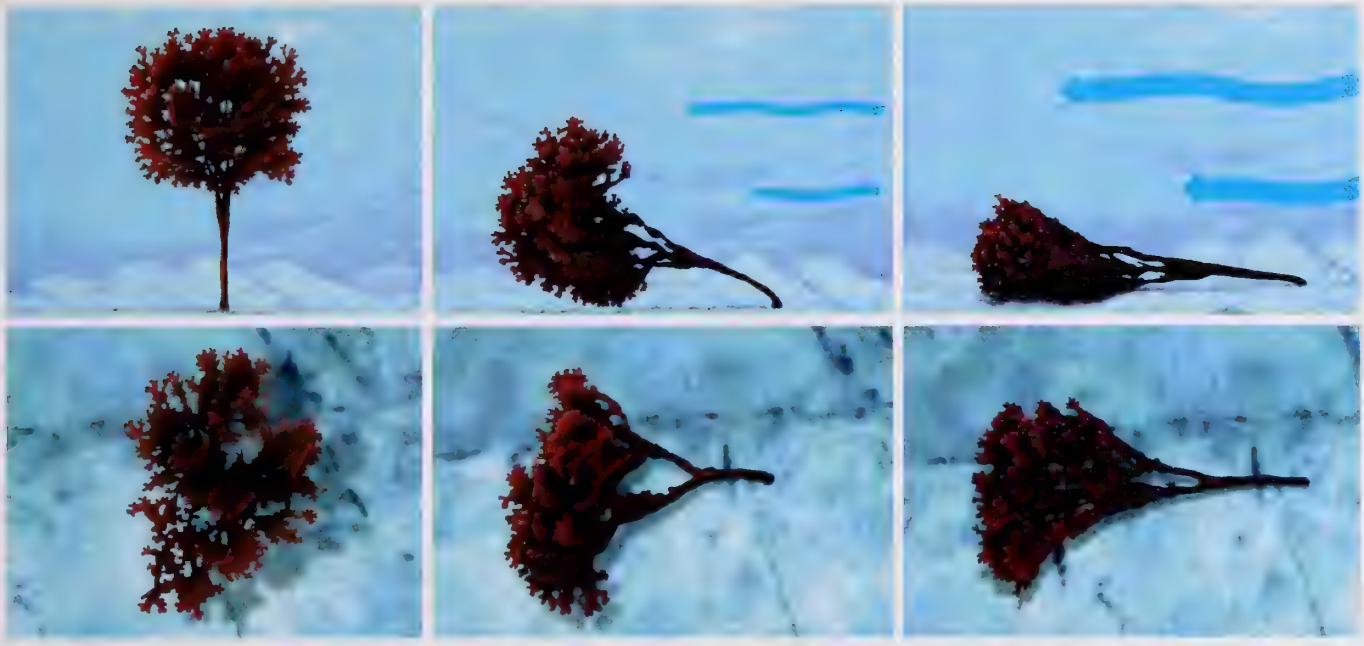
At low tide, the sun beats down and heats what little water remains in scattered pools, where oxygen levels madly fluctuate and salinity increases with each evaporative minute. When the tides change, the physiological insults ease, only to be replaced by the physical battering of the waves, which try alternately to shove things higher onto the shore and to suck them into the deep. The habitat might as well be called intertidal hell.

Yet organisms from anemones to zooxanthellae are perfectly happy here. How surf-zone denizens manage to survive the wave-swept environment could fill entire books on biomechanics. But the story of one alga's fight to hang on caught my attention.

Moving water exerts drag; no doubt you've felt it—the force that knocks you off your feet as you stand in the surf. It's the same force that scours rocks on the seashore clean of encrusting critters. In this context the drag on an organism changes with three factors: the speed of the water and the shape and the size of the organism itself. Faster water exerts a lot more force; in fact, drag varies directly with the square of velocity, so, for instance, doubling the water velocity bumps up drag fourfold. Size, or more properly cross-sectional area, also matters because the bulkier an object, the more rushing water slams into it. (A kayak pinned broadside to the current against a submerged rock is much harder to move than a kayak lodged against the rock head-on.) The way shape influences drag force is captured by the drag coefficient, a term automakers invoke so often that you might think it applies only to cars.

Creatures trying to make a living in the surf zone deal with the push and pull of waves by manipulating all three of these determinants of drag in their efforts to stay in the same general spot. Many animals hide in crevices or in the lee of a rock, where flow speeds are lower. Others take an engineer's approach to the problem: they assume the minimum size that will enclose their feeding and reproductive organs—and never budge in size or position. Thus barnacles, limpets, and chitons that fall into the fixed-shape category are stuck with the same shape all the time.

Other creatures, however, have opted for more flexibility. Two biologists, Michael L. Boller at Stanford University's Hopkins Marine Station in Pacific Grove and Emily Carrington at the University of Washington's Friday Harbor Labs on San Juan Island, are looking at how algae manage to stay attached to their rocky homes despite battering waves. Algae can't take the fixed-shape path, at least not without sacrificing an awful lot of area needed for photosynthesis. They can't trot off to the far side of the rock, either, to hide from the incoming waves. The solution, at least for some macroalgae, appears to involve tricky contortionism; they co-opt the force of the water to produce



*Irish moss responds to the speed of flowing water by changing its configuration, as seen from the side (top row) and from above (second row). In calm water it stands upright (left). Mild currents tug the alga into a cone-shaped position, which still allows for photosynthesis but minimizes drag (middle). In extreme conditions, the alga bends down and compacts even further into a streamlined form (right) that may prevent it from becoming detached or torn apart.*

changes in their own shape that simultaneously reduce their area and their coefficient of drag.

Boller and Carrington worked with a common alga of New England and European surf zones, Irish moss *(Chondrus crispus)*. Though called a red alga, Irish moss can range from dark purple to yellowish green, and it is shaped like a miniature tree about eight inches high [*see illustrations above*]. (It is also a source of carrageenan, a thickener used in ice cream—and anything to do with ice cream is relevant to my kind of biomechanics.) They collected Irish moss samples of various size and shape, and glued their bases—appropriately called holdfasts—to a platform that could measure drag force. Then they submerged the platform in a flume, the aquatic equivalent of a treadmill, and measured the drag force as they changed the flow speed from a gentle lapping to a punishing postgale surge. As the flow speed increased, the algae morphed into lower-drag shapes.

In still water the algae stood tall and bushy, with lots of area for the sun to stimulate the chloroplasts. In moving water the algae took two different positions, depending on the strength of the flow. In languid washes, each stipe—an algal analog to the trunk of a tree—bent over, so the algae's foliage brushed the bottom of the flume. The change decreased the area presented to the flow and reshaped the algae from upright tree to pointed cone. At that stage, because drag forces were relatively low and the algae's canopies were still largely exposed, it's likely a good deal of photosynthesis could still take place.

At faster flows, the algae morphed even more. As the flow speed rose, the canopies of the Irish moss became increasingly compact—each narrowing into a cone with an area less than half of its shape in still water. Furthermore, the shape changes enabled the algae to hide their canopies in their own flow shadows and thereby slightly lower the drag coefficient. No question, the drag force on the algae increased with the speed of the flow, but not as fast as it would have without the change in shape. Above a certain velocity, however, the algae reach a point where they cannot get any smaller. Carrington and Boller aren't sure how much the final, squeezed shape affects photosynthesis; prolonged exposure to fast water can't be good, but the organism can certainly weather the occasional storm.

No amount of reconfiguration on the part of the Irish moss can keep up with a force change that depends on the square of water velocity—the drag continues to increase with water speed until the current finally washes the algae away. But by allowing the stipe and canopy to go with the flow, the holdfast is usually saved from being ripped from the rock. It brings to mind blustery days I've spent at the rocky shore. Considering my size, my area, and my high drag coefficient I would have done better positioning my posterior to the wind, and taken shelter in my own not inconsiderable bulk.

*Adam Summers* (asummers@uci.edu) *is an assistant professor of bioengineering and of ecology and evolutionary biology at the University of California, Irvine.*

NATURAL HISTORY
JULY/AUGUST 2006

# The Scaly Ones

*Squamata—lizards and snakes—have spread to almost every landmass and branched into more than 7,200 species. Ecological and molecular studies are bringing their family tree more clearly into focus.*

By Laurie J. Vitt and Eric R. Pianka

They climb walls and scuttle upside down across ceilings, dive to the ocean floor to feed on algae, even glide through the air from treetops. Some, with no limbs and extremely long tails, look like snakes; others are snakes. Many are nearly invisible in their home habitats; others announce their presence to their neighbors and warn off potential rivals by flashing colorful dewlaps, or fanlike structures, that lie just underneath their lower jaws [*see photograph on page 32*]. They dine on everything from microscopic insects to hefty animals. Some wield lethal toxins through long, hollow fangs. They are members of the order Squamata, "the scaly ones," more popularly known as lizards and snakes. They are also one of the most successful orders of tetrapod (four-legged) vertebrates on Earth. In some people they provoke a phobic reaction (particularly the snakes). But we, among many others, find them irresistibly fascinating. Then again, our interest is also a professional one: we have devoted our careers to them.

What particularly fascinates us is how, long ago, a common ancestor of squamates could have given rise to so many diverse descendants. Their living representatives—numbering more than 7,200 species—inhabit every continent except Antarctica and even many oceanic islands. When we look at them, we know that some of their similarities and differences reflect recent evolutionary adaptations, made in response to other species in their present-day environments. Other characteristics are a legacy of more ancient adaptations in response to unknown conditions—early choices that set various groups on separate evolutionary trajectories.

But with so many species and habitats, how can one reconstruct the group's evolutionary history? Fossils tell only a limited story, and they are relatively rare. (Many of the ancestral species were small, and so their bones were less likely to be preserved—and more likely to be overlooked by paleontologists seeking bigger, more spectacular finds.) Investigators have barely begun to probe the genetic data that might bring us closer to understanding the evolutionary relations among living groups. But we think enough clues exist to sketch a coherent story.

Our story begins when squamates and their nearest relatives, the Rhynchocephalia ("beak-headed" reptiles, so named because their jaws have a beaklike tip) split from a common ancestor. According to Susan Evans, a paleontologist at University College London, the branching probably took place sometime during the Lower or Middle Triassic periods, between 251 million and 228 million years ago. At that time Earth's landmasses were united in one supercontinent, Pangaea. No one can be sure exactly when the split occurred, because the earliest known squamate fossils date only from Lower Jurassic sediments, between 200 million and 175 million years ago, but those fossils suggest the group had already been evolving on its own for some time. Another reason paleontologists think squamates are older than their oldest known fossils is that earlier fossils have been discovered belonging to their "sister" group, the rhynchocephalians. That group was widespread and diverse before the end of the Middle Triassic, but only two descendants have survived to the present: they are the two species of tuataras that occur in New Zealand.

The common ancestor of squamates and rhynchocephalians was likely a small lizardlike reptile that ate insects and spiders. Although many skeletal features distinguish squamates from their sister group, one of the most important is found in the lower jaw. In the common ancestor, the lower jaw rotated from a pivot point on the bottom rear of the skull, which otherwise was relatively rigid. With the evolution of squamates, the skull bone that connected to the lower jaw—the quadrate—became only loosely attached by ligaments to the rest of the skull. That new hingelike configuration, known as streptostyly, enabled the back of the jaw to move more freely [*see illustration on page 31*]. In practice, it enabled the animal to deliver a faster and more powerful bite, and perhaps to open its mouth wider as well, making it much easier for ancestral squamates to capture and handle prey.

Sometime between 30 million and 60 million years after the split between squamates and rhynchocephalians, the squamates themselves split into two major groups, Iguania and Scleroglossa. Fossil evidence for the timing of that split is sparse, but it is consistent with the amount of divergence evident in the DNA of living species—a question investigated by J.

*An overfed, captive day gecko* (Phelsuma madagascariensis) *from Madagascar licks the transparent scale covering its eye. Lacking eyelids, the gecko cleans its eyes with its tongue. Another gecko parlor trick is walking upside down, thanks to many millions of microscopic filaments that make up the surface of its toe pads.*

Robert Macey, a molecular biologist then at Washington University in St. Louis, and his colleagues. Intriguingly, the split appears to coincide with the breakup of Pangaea into two supercontinents, Laurasia and Gondwana.

For some time, paleontologists reasonably theorized that that event, by separating two populations of squamates, initiated the evolutionary divergence of the two major groups. Investigators now know that early fossils of both groups were deposited in both zones of Pangaea before the land mass broke up. Nevertheless, that geological event apparently bore some relation to the evolutionary one. Most of the early diversification of iguanians took place on Gondwana, the southern continent, whereas most of the early diversification of scleroglossans took place on Laurasia, the northern continent. Why that is, however, remains unclear.

When Iguania and Scleroglossa diverged, iguanians retained most of the characteristics of their squamate ancestors. Iguanian skulls remained relatively rigid. They continued the early squamate lifestyle of lying in wait for prey and remaining cryptic—hidden or camouflaged—except when pursuing prey. And they continued to rely on vision to detect and discriminate prey and on what Kurt Schwenk, a functional anatomist at the University of Connecticut in Storrs, calls lingual prehension—literally, holding with their tongues—to capture and manipulate prey. Schwenk argues that lingual prehension was the ancestral mode of feeding in tetrapod vertebrates, and so in squamates it may represent the inheritance of a very ancient trait.

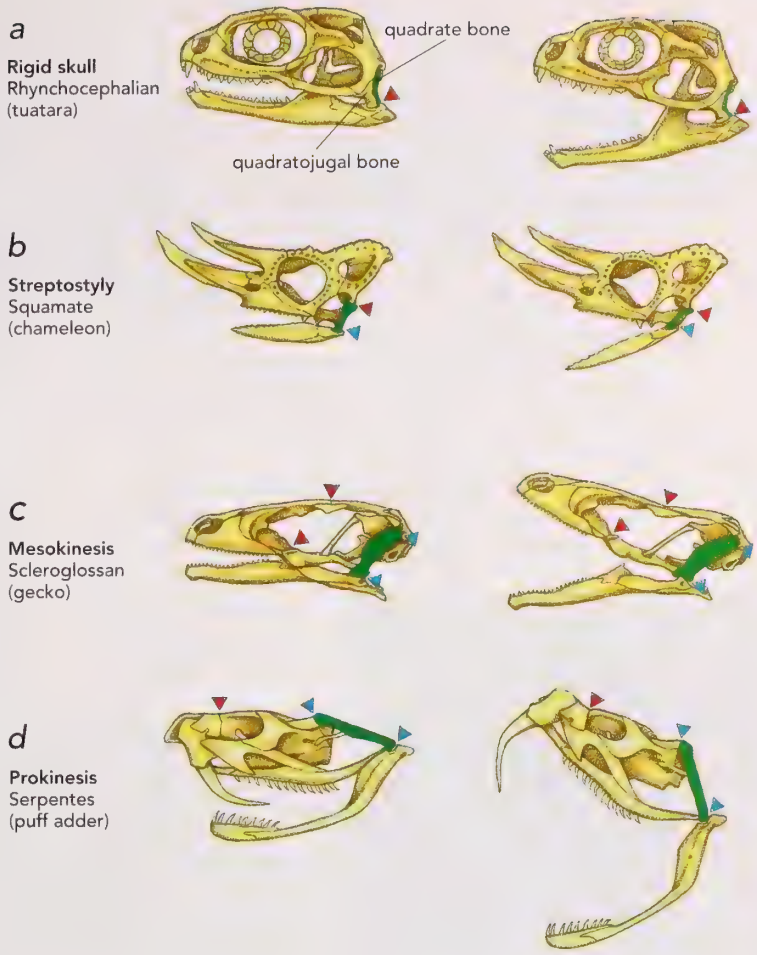
The diversification of iguanians has been spectacular. Today they include most insect-eating lizards that tend to pursue their prey from fixed perches, such as chameleons; many other insectivorous species; and nearly all large plant-eating lizards around the globe—including iguanas, the group's namesake. Among iguanians is *Moloch,* the thorny devil of Australia [*see photograph below*], a

*Australian thorny devil* (Moloch horridus), *a lizard in the family Agamidae, specializes in eating ants, which it captures with its sticky tongue. Otherwise harmless, the lizard, shown here about life size, protects itself by sporting spiny scales, changing its coloration to match its background, walking slowly and jerkily (or freezing in place), and holding its tail erect (which may make the animal look like a plant). When threatened, it puffs up and bends its head down between its legs, exposing the peculiar hump, or "false head," on the back of its neck, instead of its real head.*

lizard that specializes in preying on ants and is so unusually shaped and well camouflaged that even experienced lizard biologists have difficulty spotting them.

Of the insect-eaters, chameleons have adopted the most extreme form of the ambush lifestyle. Chameleons have nearly eliminated pursuit; instead, they have a propulsive tongue that is often longer than their body [*see photograph on pages 34–35*]. A chameleon creeps within range of its insect prey, then hurls its tongue explosively at it. The prey sticks to the tongue, then gets rapidly pulled into the chameleon's mouth. All the while, the chameleon remains otherwise immobile, hidden by its cryptic shape and coloration. One of the main advantages of that strategy is that it reduces risk: when an animal moves, potential predators may see it. The strategy also saves energy: shooting forth the tongue "costs" less than chasing down prey.

If there is a downside to the iguanian lifestyle, it is being tied down to real estate that matches the animal's camouflage. A lizard that looks like a leaf can be nearly invisible in a bush, but it stands out on a rock. So the need for camouflage has doubtless played an important role in the evolution of iguanian social behavior. Most iguanians are territorial, fiercely defending areas where they blend in. There they remain unless another of their species usurps the favored place.




*Joints of the skull and jaws (arrows) help distinguish members of the order Squamata (lizards and snakes) from one another and from members of the closely related order Rhynchocephalia. Skull of a tuatara (a), a member of the order Rhynchocephalia, is relatively rigid. The lower jaw pivots from the lower end of the quadrate bone (green) and the adjacent quadratojugal bone. In skulls of squamates, including chameleons (b), the jaw pivots from the lower end of the quadrate. The upper end of the quadrate bone also enjoys some freedom of movement, a condition known as streptostyly, making it possible for the animal to move the rear of the lower jaw more freely in manipulating prey. Many squamates have an additional joint in the skull that enables the muzzle to flex upward and downward. In most lizards (c), that joint is behind the eyes (mesokinesis), but in snakes (d), it lies in front of the eyes (prokinesis). Snakes have other flexible skull and jaw joints; the viper (d), for instance, can also rotate its upper jaw bones that hold the fangs.*

In sharp contrast to iguanians, scleroglossans evolved in ways that enabled them to capture and manipulate prey with their jaws, an ability that Schwenk calls jaw prehension. That strategy freed up the tongue for tasks other than capturing prey, and the tongue became firmer as a result (*scleroglossa* means "hard-tongued"). Among the early adaptations in this group was the addition of a joint in the top center of the skull that enabled the upper jaw to bend upward and downward (try doing that with your upper jaw!). The flexible movement in the middle of the skull, known as mesokinesis, greatly increased biting efficiency by allowing the upper jaw to move downward as the lower jaw closes from the bottom up [*see illustration on this page*]. Snakes have a similar hinge, but it is in front of their eyes (a condition known as prokinesis). They also have additional flexible joints, such as one at the front of the muzzle that enables the left and right bones of the upper jaw and palate to move independently (that is what makes it possible for a snake to "walk" its head down over a large item of prey). Another important innovation in snakes is a loose, stretchable cartilaginous ligament that joins the front tips of the right and left lower jawbones: that allows the bones to move apart, enabling snakes to swallow exceedingly large prey (recall the drawing of a snake in *The Little Prince*).

Switching from tongue to jaws for capturing prey might not seem groundbreaking. The change freed the tongue for other functions, however, and likely

set the stage for the evolutionary enhancement of the vomeronasal organ, a chemosensory organ embedded in the roof of the mouth. That organ detects heavy, nonairborne molecules taken in through the mouth. It supplements nasal olfaction, which is the ability to smell airborne molecules that enter through the nostrils as the animal breathes. It is distinct as well from taste, which is the ability to analyze chemicals with taste buds on the tongue. In scleroglossans the enhancement of both olfaction and vomerolfaction was life-changing: not only could they rely less on sight to detect prey, but they could also perceive sex and sexual receptivity in their own species on the basis of chemical cues alone.

The avid way Gila monsters hunt out eggs suggests that enhanced chemical senses have helped some scleroglossans to find prey particularly rich in energy. But perhaps more important, the enhanced sense of vomerolfaction also enabled scleroglossans to identify dangerous prey—prey whose metabolic poisons or other defensive chemicals could be deadly or at least costly to digest. Several years ago we combined data we had gathered independently over our careers and demonstrated that, compared with iguanians, scleroglossans eat many fewer ants, other hymenopterans, and beetles, most of which produce noxious or toxic chemicals. Most scleroglossans are highly active, and so they encounter numerous potential prey; that behavior may afford them the luxury of passing over noxious insects.

*Male fan-throated lizard from India* (Sitana ponticeriana), *pictured 1.3X larger than life size, flashes its blue, black, and red dewlap to defend its territory from others of its species. The animal relies in large measure on camouflage for its own protection as well as for ambushing insect prey, and so it must not cede suitable habitat to another lizard without a fight.*

As evolving chemical senses enabled scleroglossans to locate prey and potential mates without relying on vision, they adopted a more mobile searching strategy. This made them more conspicuous, requiring wariness, speed, and agility—not just camouflage—to escape predators. For the most part they ceased devoting time and energy to defending territories. Their chemical senses also enabled some scleroglossans to enter subterranean microhabitats and others to shift to nocturnal habits, both unavailable to iguanians that rely on vision as their primary sensory system.

One possible measure of the success of the shift to jaw prehension and chemical senses is that in terms of extant species, scleroglossans outnumber iguanians 4.5 to 1. That ratio might overstate an advantage resulting mostly from chance. For example, scleroglossans could have split into separate groups a bit earlier than iguanians did in their evolutionary history, and the present-day diversity might simply magnify that small advantage. But scleroglossan success was real. A more convincing measure is that scleroglossan species outnumber iguanian species at nearly every site where both occur. In most places, scleroglossans dominate the ground, foraging freely over the landscape, whereas most iguanians are confined to rocks, shrubs, tree trunks, or other more restricted habitats.

Subsequently—about 180 million years ago—scleroglossans split into two groups, Gekkota and Autarchoglossa, which differ in when they are active and how they use their tongues. Gekkotans include, among others, geckos (after which the group is named) and the snakelike flap-foots of Australia. Most geckos are nocturnal. They have no eyelids; instead, the eye is covered by a "spectacle," or transparent scale, similar to the eye-covering of snakes. The tongue serves as a windshield wiper to clean the spectacles (as well as the lips). Geckos also have a good sense of smell. William E. Cooper Jr., a biologist at Indiana University–Purdue University in Fort Wayne, has shown that geckos detect airborne pheromones of other geckos, and discriminate prey on the basis of chemical signals.

Geckos are also noted for being able to scale vertical surfaces and walk upside down on leaves, rock faces, and trees. They can even jump from tree to tree by catching a leaf on the second tree with a toe. Although some other lizards (anoles and a few skinks) can climb vertical surfaces with their toe pads, none are as adept as the geckos. Kellar Autumn, a biologist at Lewis & Clark College in Portland, Oregon, has shown that gecko feet stick to surfaces by van der Waals forces, a form of molecular attraction. Their toe pads have ridges, each ridge

*Flap-foot* (Lialis burtonis), *a snakelike, virtually limbless lizard shown here about two times life size, specializes in eating other lizards, which it swallows whole. It has an extremely flexible joint in the middle of the skull, which enables it to raise and lower its upper jaw when catching and killing prey.*

covered with thousands of setae, hairlike structures that branch into hundreds of microscopic endings, called spatulae, that maximize contact with a surface.

Flap-foots belong to the Australian family Pygopodidae. Pygopodids are elongate lizards with no forelimbs and greatly reduced hind limbs. Some are burrowers, others terrestrial or arboreal. Many flap-foots swim through grass tussocks. Some are nocturnal, others diurnal. Some mimic venomous snakes in coloration or by acting menacingly.

One flap-foot, *Lialis*, acts more like a snake than it does other lizards in that it swallows very large prey, including other lizards. Skinks, *Lialis*'s primary prey, are armored with bony plates known as osteoderms embedded in their scales, and so, like some skink-eating snakes, *Lialis* has evolved hinged teeth. When a tooth hits an osteoderm, it folds, whereas a tooth that goes between scales remains erect, giving it good purchase. As the skink squirms and wiggles in the jaws of *Lialis*, it literally ratchets itself down the predator's gullet.

Autarchoglossans, "independent tongue" reptiles, pick up heavy, nonairborne chemicals from surfaces

*Cladogram, a diagram that shows evolutionary branching points, depicts probable interrelations among living families and other large groups in the order Squamata, as well as their shared ancestry with the Rynchocephalia, once a much more widespread and diverse group. Within squamates, iguanians have prehensile tongues for capturing prey, an ancestral feature lost in scleroglossans. Autarchoglossans use their tongues to pick up heavy, nonairborne chemicals and deliver them to the vomeronasal organ, a sense organ in the roof of the mouth.*

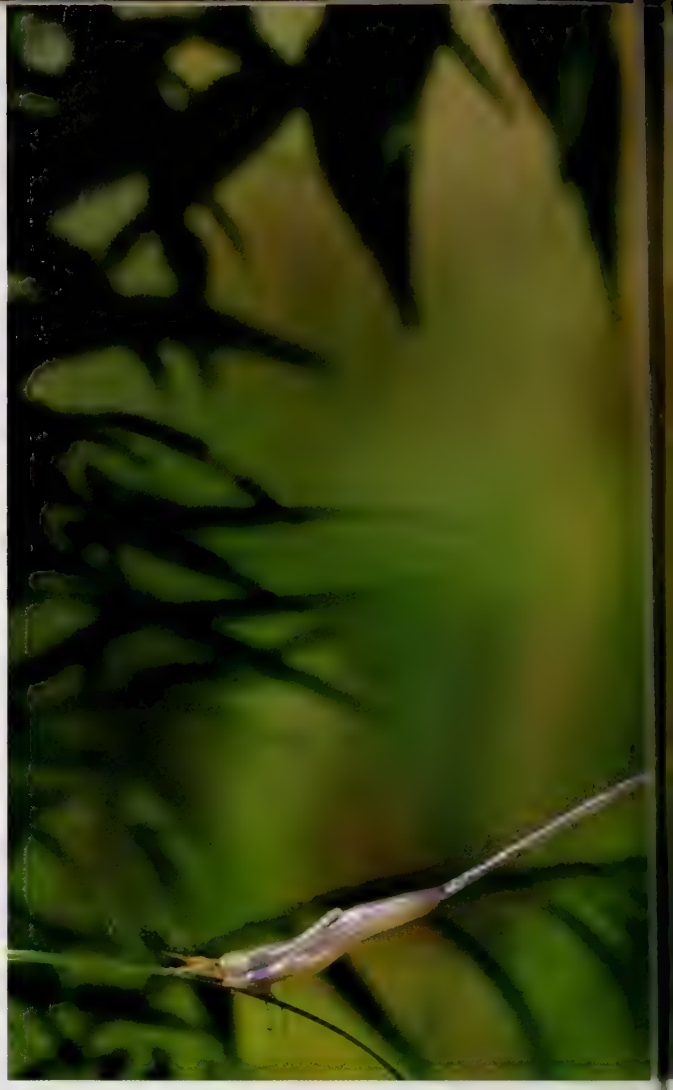
with their tongues. The tongue then deposits the chemicals on the vomeronasal organ. Among the autarchoglossans are tegus and whiptail lizards, which march around in the hot sun in deserts and open tropical habitats of the New World, sticking their faces under surface objects to find insect larvae, digging into termite nests to feast on hundreds of termites, and even finding and eating carrion, all without relying primarily on vision. Other prominent members of the group are anguids, such as alligator lizards; Gila monsters; lacertids, such as jeweled lizards; monitor lizards; skinks; and all snakes.

The long, thin tongues of monitor lizards and snakes take chemical sensing to its most sophisticated level. Not only can they discriminate chemicals, but by comparing chemical dosages picked up on each fork of the tongue, they can detect edges as well as the direction of a chemical source. Just as chameleons are the logical endpoint to the evolution of a sit-and-wait foraging strategy, snakes might be considered the logical endpoint within a group of organisms that have highly flexible skulls and a well-developed chemosensory system for locating and discriminating prey.

And just as scleroglossans seem to have elbowed iguanians out of terrestrial habitats, so too autarchoglossans seem to have pushed gekkotans off the ground—or at least into a nocturnal lifestyle. Although one group of autarchoglossan lizards, the snakes, includes many nocturnal species (most from warm regions), autarchoglossans are generally active by day. In fact, their high activity levels usually require a high body temperature. Gekkotans operate at lower body temperatures, but their nocturnal habits have limited their distribution to regions that are warm enough at night. Most geckos, for instance, live in the tropics or in deserts, and only a few live in colder climates.

Autarchoglossans also continued another tradition of their scleroglossan ancestors. Whereas chemical senses had enabled the scleroglossans to expand their ranges and relax their need to defend territory where they were camouflaged, the continuing evolution of those senses enabled the autarchoglossans to forage in places where they could not see. And in several families of autarchoglossan lizards, species evolved that dug burrows and lived underground.

In many cases the subterranean lifestyle led to the evolutionary loss or reduction of limbs and to shortened tails. In some species, eyes were reduced to simple light-detecting organs—the animals had essentially shifted to a world dominated by chemical signals. Other lineages evolved elongate bodies and tails, even as limbs were lost or reduced, giving



rise to what are known in the United States as glass lizards (genus *Ophisaurus*). (The common term "glass lizard," however, can refer to species in several families of lizards that have evolved independently on different continents.) Neither limblessness nor subterranean activity has ever evolved in iguanian lizards.

That brings us to snakes, which are characteristically limbless. Although they figure large in people's lore and imagination, snakes are simply one evolutionary group (Serpentes) of scleroglossan lizards. They are closely related to lizards that belong to the family Varanidae, which comprises the Komodo dragon and other monitor lizards. They may have descended from a varanidlike ancestor, and a common assumption is that they evolved from some burrowing terrestrial lizard. Another theory, however, is that the first snakes were aquatic, having evolved from the mosasaurs, an extinct group of large marine reptiles that were also closely related to the varanids [*see "Terrible Lizards of the Sea," by Richard Ellis, September 2003*]. But even if terrestrial snakes descended from an aquatic ancestor, herpetologists generally agree that today's species of aquatic

*Veiled chameleon* (Chamaeleo calyptratus), *like other chameleons, captures insects at great distances with its tongue, which in this individual extends about ten inches. Chameleons are iguanians, most of which manipulate prey with the tongue, though a few are vegetarians. Members of the other major group of squamates, the scleroglossans, capture prey with their jaws.*

snakes have all descended from terrestrial snakes.

What a snake can find is limited only by the size of crevice or hole that it can stick its head into; what a snake can eat is limited in size only by how far it can disarticulate one of the most flexible skulls known in vertebrates. As a result, snakes have become top predators, coming back to haunt such close evolutionary relatives as the lizard autarchoglossans as well as iguanians and gekkotans. Many snakes produce venoms, with which they kill large prey and retaliate against would-be predators. So do some lizards, such as the Gila monsters [*see "Venomous Lizards of the Desert," by Daniel D. Beck, July/August 2004*]. Some snakes (including pit vipers, many boa constrictors, and some pythons) have heat-sensing pits in one or more scales along the jaw, wired directly into the optic neural system, which essentially enable them to see in the dark by detecting changes in the thermal landscape.

Many venomous snakes have brightly colored rings (as do Gila monsters) that warn potential predators that they are dangerous. A host of nonvenomous snakes have evolved color patterns that mimic those of venomous species, thereby taking advantage of the protection a venomous reputation affords against potential predators. People are among the many large animals that instinctively give snakes a wide berth. The threat of a venomous snake, not to mention the dangers posed by large constrictors, probably ingrained that instinct in our early mammalian ancestors.

Whether we are attracted or repelled by snakes and other squamates, we owe the group respect for its evolutionary success. Along with turtles and crocodilians, they are the reptiles that we see around us today. Dinosaurs, ichthyosaurs, plesiosaurs, and pterosaurs were impressive in their time, but all (except for birds) were long gone before humans came along, as much as we might fantasize about "lost worlds." Squamates, on the other hand, watched the dinosaurs come and go. Chances are they will be around to watch humans exit as well. □

# From Fins to Limbs

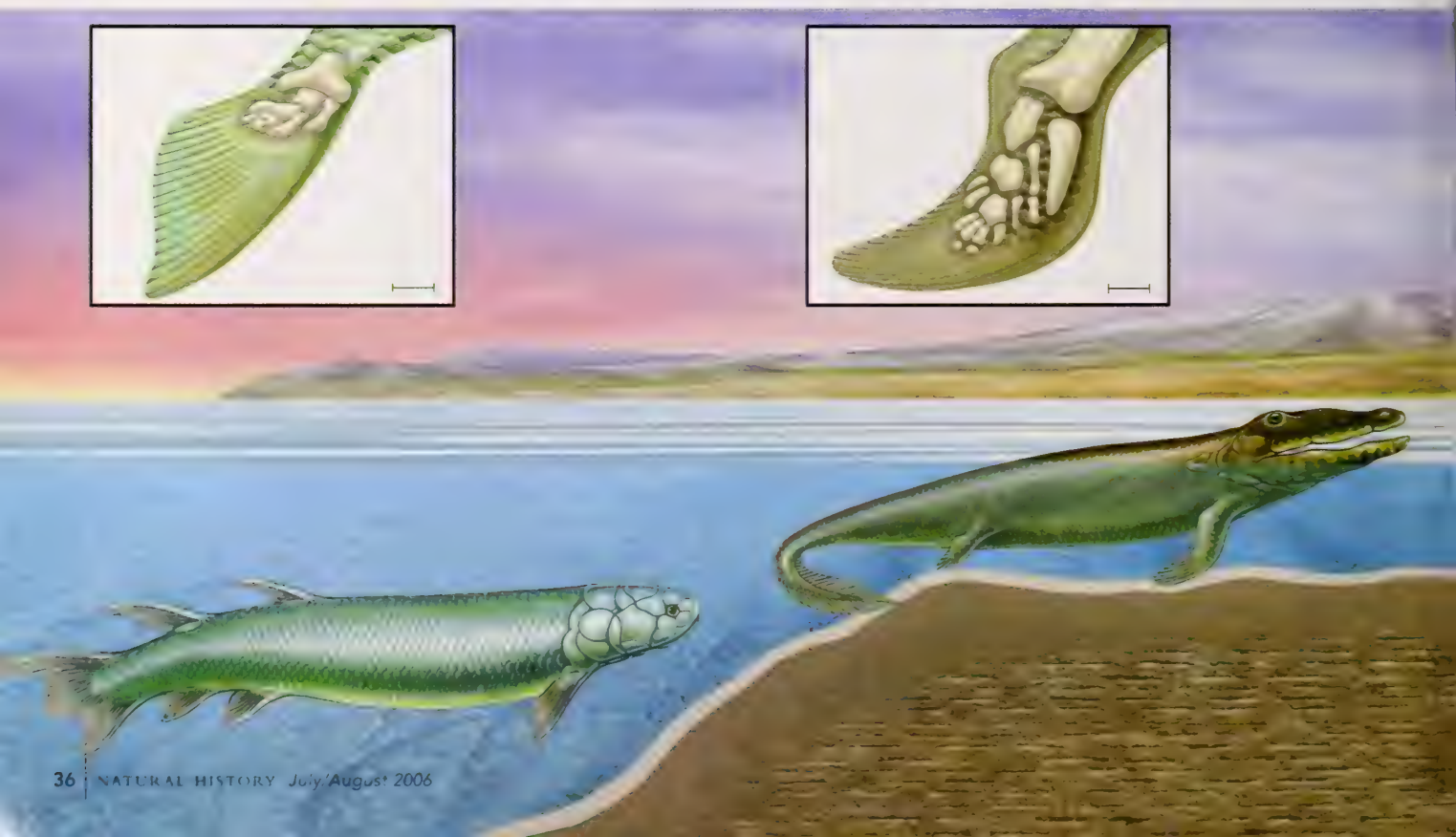
*Recent fossil discoveries show how four-legged land animals evolved from fishes whose finlike paddles had already adapted to functions such as pushing through shallows and swamps.*

By Jennifer A. Clack

When I became a paleontologist about twenty-five years ago, the evolution of four-legged animals from their fish ancestors was embodied in *Ichthyostega,* a partly terrestrial creature that lived 360 million years ago in what is now East Greenland. *Ichthyostega* was the oldest known tetrapod—an animal having four legs with toes. On the other side of the evolutionary divide was *Eusthenopteron*, a fish that was about ten million years older than *Ichthyostega.* In *Eusthenopteron* paleontologists saw the model ancestor to the tetrapods: the skeleton of its fin seemed the archetype from which all limbs evolved, including our own.

Those two iconic animals stimulated speculation about how creatures crawled out of the water to "conquer the land." According to the simplest scenario of the day, a fish such as *Eusthenopteron* left one drying-up pool to find another and thus grew legs. But *Eusthenopteron* and *Ichthyostega* were only two widely separated points of reference; the intermediate steps were missing. And little could be said about what encouraged animals onto land, how the transition happened, or when it took place.

*Ichthyostega* had first come to light in the early 1930s. In 1897 a party of explorers known as the Andrée expedition, traveling by balloon, had been lost attempting to find the Northwest Passage—the fabled navigational shortcut across the top of the world. Decades later, Scandinavian scientists were searching for the remnants of that expedition in East Greenland, when they found a cache of *Ichthyostega* fossils, among other geological discoveries. After that, Greenland be-



came a magnet for competing Scandinavian geologists, with *Ichthyostega* as one of the prizes.

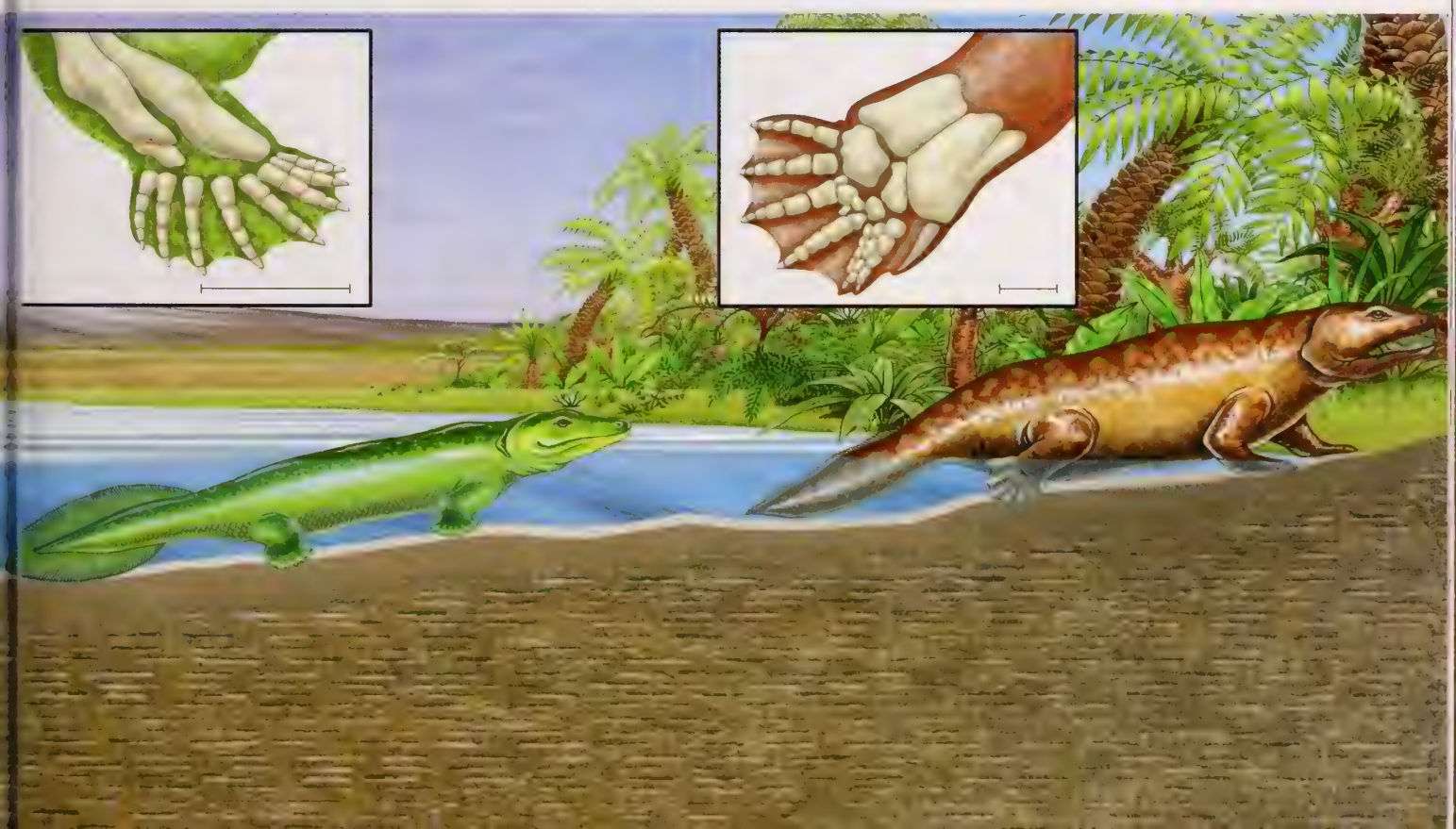
At the time of *Ichthyostega*'s discovery, another creature from East Greenland, called *Acanthostega*, was known; it had been identified in the 1940s as a second kind of early tetrapod, on the basis of two incomplete skulls. Those tantalizing skull fragments were from the same time (and, evidently, the same place) as the fossils of *Ichthyostega:* from the Late Devonian, about 365 million years ago. Because of the movements of continents driven by plate tectonics, Greenland has not always been an Arctic island; in the Late Devonian, it was part of a huge landmass at the equator and was rich with the life-forms of the period [*see map on next page*]. Hence Greenland beckoned to paleontologists as the probable site of one of the great events in the history of life on earth.

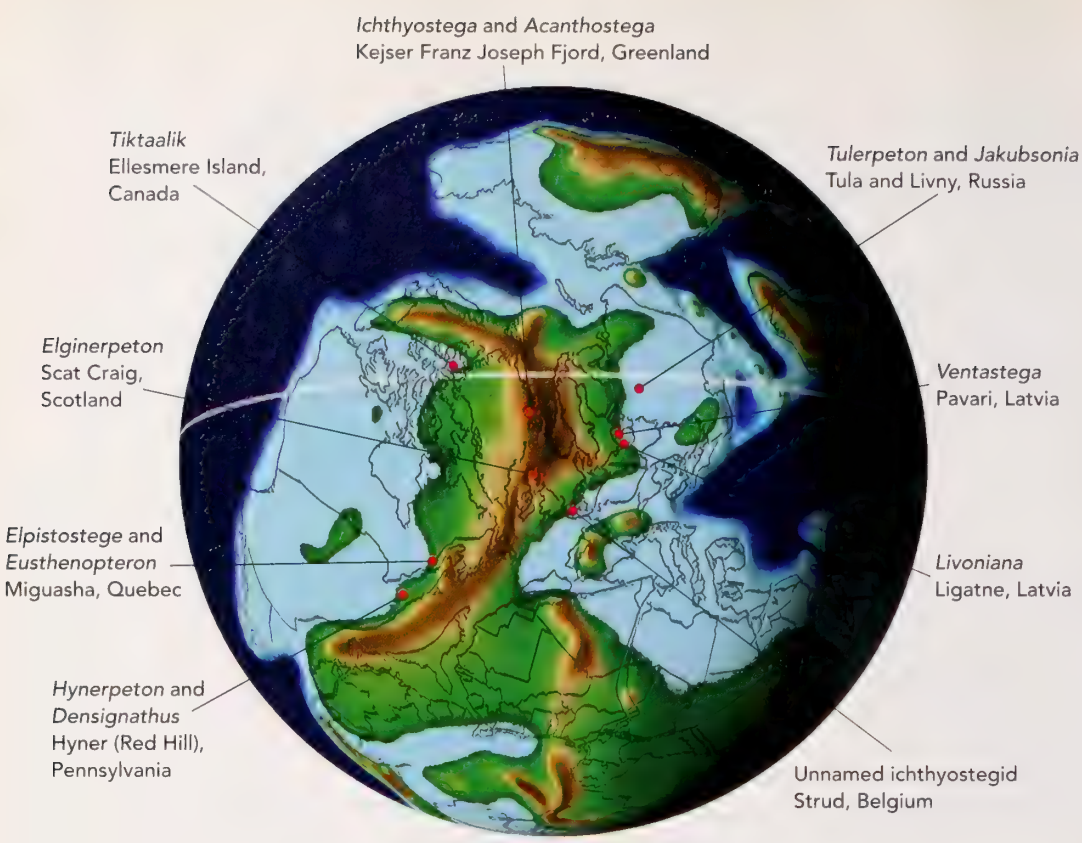
In the summer of 1987 I was fortunate to get the chance to explore several places in central East Greenland where more Devonian tetrapods were likely to be found. Mounting a Greenland expedition was a daunting prospect for a novice like me. It required ample stores of food, a radio-support network, helicopters to get in and out of the region, and firearms to ward off polar bears and musk oxen. As luck would have it, a team of Danish scientists from the Greenland Geological Survey was completing a three-year project in the same area my colleagues and I wanted to explore and had all the logistical resources in place to serve our expedition. Thanks to their good offices, the expedition was blessed with success.

We pinpointed a prime site 2,600 feet up a steep mountainside. During our first days in the field, the climb to the site took us most of a day, but by the end of four weeks, we could scramble up in just two and a half hours. With twenty-four hours of daylight, we could spend a long spell on the mountain. The fossils we discovered were well worth the effort; on returning from the field, we had enough of them to recreate the anatomy of *Acanthostega* and its mode of locomotion. And in the same general location, though in slightly different sediment beds, we found a few remains of *Ichthyostega.* The story of the transition from water to land began to gather momentum.

The Greenland fossils and subsequent discoveries

*Aquatic tetrapods, or four-legged swimmers, evolved during the Devonian period (between 416 million and 359 million years ago) to become the first four-legged land animals, as fins were transformed into limbs with fingers and toes. The four animals shown below (not to scale) are (left to right):* Eusthenopteron, Tiktaalik, Acanthostega, *and* Ichthyostega. *Limbs might have given an advantage to transitional forms such as* Tiktaalik *in navigating swampy waters or in pushing across the bottoms of riverbeds; eventually, the limbs of some tetrapods became able to bear weight on land. The insets show the creatures' right forelimbs (except for* Ichthyostega, *which is a right hind limb); the scale bars each represent one inch.*






*Continents and oceans of the Late Devonian epoch (between 385 million and 359 million years ago) were situated as shown on the map. The regions that later became modern-day countries and continents are also outlined. In general, landmasses in the Late Devonian were farther south and more concentrated around the equator than they are today. Tetrapods and their closest relatives have been discovered at the sites indicated by colored dots, and also occur in China and Australia (not shown).*

have forced paleontologists to rethink virtually every piece of "settled" knowledge about the origin of four-legged animals. Not only is there a new understanding of the anatomical innovations embodied by *Ichthyostega* and *Acanthostega*. But more, paleontologists have assembled a picture of the global distribution of Devonian tetrapods, as well as the extent of their diversity, that was unthinkable even a decade ago. One of the most exciting new fossils is *Tiktaalik*, a fish-tetrapod "missing link" whose discovery in the Canadian Arctic by paleontologists from the National Academy of Natural Science in Philadelphia and from the University of Chicago made front-page news this past April. Although no single fossil can fully explain a complex evolutionary event, *Tiktaalik* is a true intermediate form, and it provides vital clues to the when, where, and how of the transition from water to land.

Back in my laboratory at the University Museum of Zoology in Cambridge, England, we examined our haul of *Acanthostega* fossils. *Acanthostega* turned out to be not terrestrial, but aquatic. It had short ribs, uniformly shaped vertebrae, and a tail with an oar-shaped fin supported by bony fin rays. It also breathed with its gills, like a fish. *Acanthostega*'s two-foot-long body could readily bend from side to side as it propelled itself through the water with lateral movements of its tail.

One big surprise was that *Acanthostega* had not five digits on each of its four limbs, but eight. So there was no original template for five fingers or toes. The story that land animals evolved when fishes such as *Eusthenopteron* emerged from the water to crawl over land and later developed limbs was just that: a story. Instead, we suggested, limbs may have evolved first as paddles, which were used to swim, to spread the animal's weight across a soft, muddy riverbed, or to push through the swampy, weed-choked waters of streams and lake margins. Only later did each limb lose a few toes, become able to bear weight, and turn into a leg for walking on land.

*Ichthyostega*, too, had a tale to tell. The first specimens of *Ichthyostega* to emerge from Greenland were found by Danes but were studied mainly by Swedes. Erik Jarvik, one of the most influential of the Swedish paleontologists in the mid-twentieth century, published a reconstruction of *Ichthyostega* that remained the basis of popular and scientific conceptions of early tetrapods for decades. His version of *Ichthyostega* was a three-foot-long quadruped with a complement of specialized features, including broad, overlapping ribs and a permanently bent elbow, which seemed at odds with *Ichthyostega*'s role as a very early tetrapod. The tail, though, was finned like that of a fish and marked *Ichthyostega* as primitive.

The specimens from our 1987 expedition gave us the first clue that something was wrong with the earlier image of *Ichthyostega*. Once back in the lab, my colleagues and I prepared the *Ichthyostega* bones by removing their surrounding rock with tools such as a dental mallet and a handled needle, all under a high-power binocular microscope. We found that instead of five toes, or eight, *Ichthyostega* had seven: three tiny ones bunched together at the

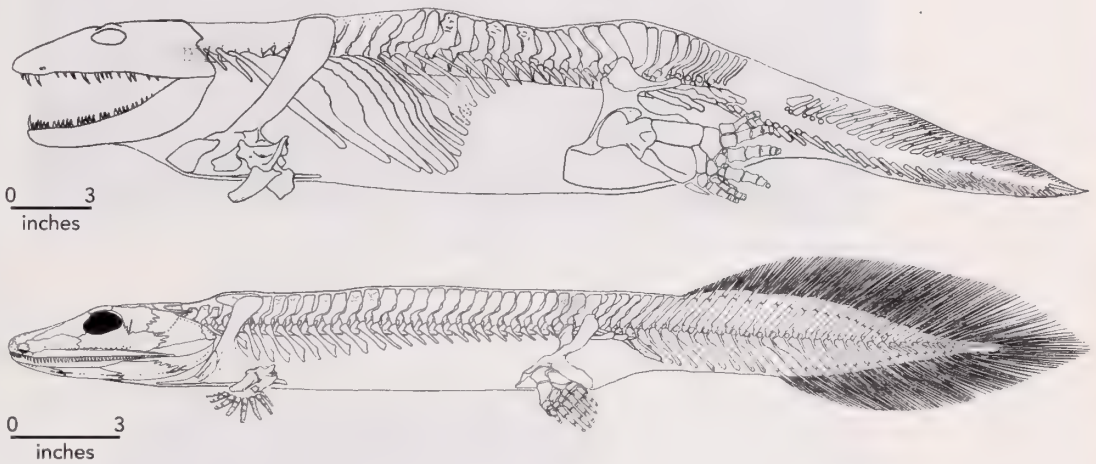
leading edge of the foot, trailed by four stout ones. Instead of a weight-bearing foot with five toes, as pictured by Jarvik, we found that the entire hind leg was shaped like a paddle [*see photograph on page 41*]. An analogous appendage, which evolved independently (and with five toes, not seven), is the forelimb of the modern river dolphin.

That discovery alerted us to other problematic aspects of *Ichthyostega*'s anatomy, as it had originally been conceived. To make accurate estimates of the relative sizes of body parts, paleontologists ideally need a head, a trunk, a forelimb, and a foot from the same individual. We lacked such a complete package; our best evidence showed that instead of having hind limbs larger than forelimbs, as in most tetrapods, *Ichthyostega* had big, strong forelimbs paired with diminutive hind limbs. Was that really the case, or was this conclusion merely an artifact of examining a composite skeleton?

To investigate further the apparent anomaly of leg size, I organized a second expedition to Greenland in 1998, aiming to find more *Ichthyostega* material. Quite by chance, all four of our team members were female, so we called ourselves the Girls in Greenland expedition. Again, we were fortunate in having the resources of the Danish geologists to help us. As so often happens in collecting expeditions, we discovered our best material in the last few days of the five-week field season, but it proved crucial. We collected shoulder, forelimb, trunk, and hindlimb bones, all from the same individual animal, which gave us the correct proportions for the limbs.

We also found a well-preserved skull from a different individual. Compared with the rest of the skeleton, skulls are complex and full of information. They not only enable paleontologists to determine relations among groups of animals, but in the case of early tetrapods, they also reflect changes that were as vital to life on land as limbs were. For example, *Ichthyostega* skulls indicated how breathing organs and ear regions derived from the gill areas of fish.

Drawing together our fresh material and the previously collected specimens in the Cambridge lab, we examined all our fossils with newer mechanical techniques and also with the newly developed process of CT scanning, specially geared to see through rock. We gave *Ichthyostega* a complete makeover. With most tetrapods, including *Acanthostega,* we could be reasonably sure which parts—ears, for instance—corresponded from one animal to another. But *Ichthyostega* was so weird in the regions at the back of the head, where the ears and brain had been, that interpreting their evolution had never been possible before. CT imaging and modeling helped us understand the anatomy of that area. We were able to conclude that the animal had a highly specialized ear that was probably adapted for use in water. For example, it might have enabled *Ichthyostega* to listen for aquatic prey. Alternatively—if we infer that *Ichthyostega* was itself able to produce sound to communicate—the ear might have helped individuals hear one another and perhaps find mates.




*Recent skeletal reconstruction of* Ichthyostega *(top) shows the unusual shape of the back, the paddlelike hind limbs, and the broad overlapping ribs. No "hands" of the creature have been found, but the "arms" and shoulders were strong and could hold up the front part of the body. A skeletal reconstruction of its contemporary, the more aquatic* Acanthostega *(above), shows a body better adapted for swimming. All four limbs were paddlelike, and the tail fin was deeper and longer than it was in* Ichthyostega.

The next part of *Ichthyostega* we reconsidered was the vertebral column, or backbone. Earlier reconstructions had shown it as made up of elements that were more or less uniform along the entire length of the backbone, as is the case in *Acanthostega.* The neural spines (equivalent to the bumps you can feel when you run your finger up the middle of your back) were all shown pointing backward and all roughly the same length. Instead, we noticed that the neural spines changed their direction progressively from the shoulder to the hip [*see upper illustration above*]. In the central, thoracic region the spines pointed conventional-

ly backward, but then, in the lumbar region, each succeeding one tilted a bit farther forward and was taller and broader than the one in front. Even farther back they began to change again, tilting backward but with a forward curve at the top. The vertebral column could thus be divided into regions, which suggests that those regions, and the muscles attached to them, were specialized for distinct jobs. Just how it all worked is not yet clear, but any spinal and muscular division of labor is extraordinary in such an early tetrapod. It occurs today only in mammals.

*Skull of* Acanthostega *is shown about three-quarters actual size. The creature had the gills of a fish and the fingers and toes of a tetrapod.*

How did *Ichthyostega* move? The most recent evidence told us that it moved like nothing we had imagined. *Ichthyostega*'s body plan would have restricted sideways bending—the lateral moves one associates with, say, *Acanthostega*, or a modern salamander. But *Ichthyostega* could have readily flexed its body up and down. It turned out that our first guesses about the hind limbs were wrong—they were not very small after all. One possibility is that *Ichthyostega* moved its forelimbs forward in tandem for a power stroke and thus inchwormed along, a gait more common in modern mammals than in modern reptiles. Think of a seal using its two forelimbs to haul itself out of the water and clamber onto a beach.

Although *Ichthyostega* and *Acanthostega* were contemporaries in the same geographic area, they lived in contrasting environments. *Acanthostega* was mostly aquatic; *Ichthyostega* was partly terrestrial. In locomotion and lifestyle, too, *Ichthyostega* was as different from *Acanthostega* as chalk is from cheese; pretty much all they have in common is four legs and the endings of their names. But beyond those two examples, the understanding of other tetrapods, their diversity, and the environments that hosted them is exploding. The 1987 *Acanthostega* fossils had unexpectedly revealed distinctive features of the teeth and jaws, features that became the key for recognizing the difference between the jaws of early tetrapods and those of the contemporary fish. We reexamined caches of previously indeterminate or largely ignored fossil fragments in museum collections. Sure enough, a series of bone fragments from Scotland, even older than the ones from Greenland, proved to be from Devonian tetrapods.

The pace of discovery picked up with further examples from Belgium, China, Latvia, Russia, and the United States. Trackways have now confirmed the presence of early tetrapods in Ireland and even in Australia. Fresh field collecting is proceeding in several of those regions, with an eye toward finding tetrapods.

In short, Devonian tetrapods have gone global. Nine species have been named, and more are in the pipeline. With the possible exception of the specimen from Belgium (which may be a close relative of *Ichthyostega*), each tetrapod is distinct and unique to its own geographic area. Some of the bones are mere fragments—strangely, mostly jaws—but the more complete specimens are showing how creatures adapted anatomically to their habitats.

But what about that first step? Which creature was the first to venture out of the water, and how, when, where, and in what circumstances was that move accomplished? Pinning down the order in which fish gained the necessary anatomical equipment would go a long way toward explaining the transition. One of the most important recent discoveries helping to answer some of the questions is not a tetrapod. It is, however, as close a relative to a tetrapod as it could be while still being fishlike. In 2005 Neil Shubin of the University of Chicago and his team discovered spectacular fossils of a "near tetrapod" on Ellesmere Island in Nunavut Territory, Canada. They named it *Tiktaalik*.

*Tiktaalik* lived between 385 and 383 million years ago and is one of three kinds of near tetrapods known from the early part of the Late Devonian. Each one lived in what were then estuaries and river channels around the coasts of the old continent of Laurussia, which straddled the equator and encompassed parts of what are now North America and northern and eastern Europe. Their presence suggests that tetrapods originated in that region, perhaps just a short time later, geologically speaking. The earliest evidence of limbs comes from de-

posits in Scotland that are around 376 million years old. Taken together, the evidence seems to peg the origin of tetrapods neatly to a period of less than ten million years in the Late Devonian, and to a recognizable geographical area.

Because of its nearly complete preservation, *Tiktaalik* has also answered major questions about the order in which tetrapodlike physical features arose, and perhaps even what they evolved to do. Changes to the head came first, in response to a greater reliance on air breathing. *Tiktaalik* had lost a series of bones that join the head to the shoulder in fishes and that protect and help operate the gill-breathing system. Thus, *Tiktaalik* had a neck—an outstanding tetrapod feature. The neck gave the head a greater range of movement, enabling the animal to raise its head out of the water to gulp air. Compared to *Eusthenopteron* and similar fish, the pocket in which air was exchanged or stored had become enlarged, and some of the gill apparatus was already evolving toward the configuration that tetrapods eventually used for hearing.

Crucially, though, the forelimbs of *Tiktaalik* combine traits of fishes and tetrapods. Although its fins still had fin rays and webbing, they were much shorter than those of its nearest fish relatives. The skeletons of the fins were robust and flexible in much the same ways as tetrapod limbs. The fins could have served as props for the body—*Tiktaalik* had enlarged ribs that served as a kind of scaffold for trunk musculature that stiffened the body—as well as a rudimentary means of walking. The fin bones, however, were still more similar to the fin bones of closely related fishes than to the digits that eventually evolved in the earliest tetrapods. *Tiktaalik* helps confirm that key anatomical changes took place while the animals were still technically fish, and that developments to the limbs began with modifications in function, before the main changes in form evolved.

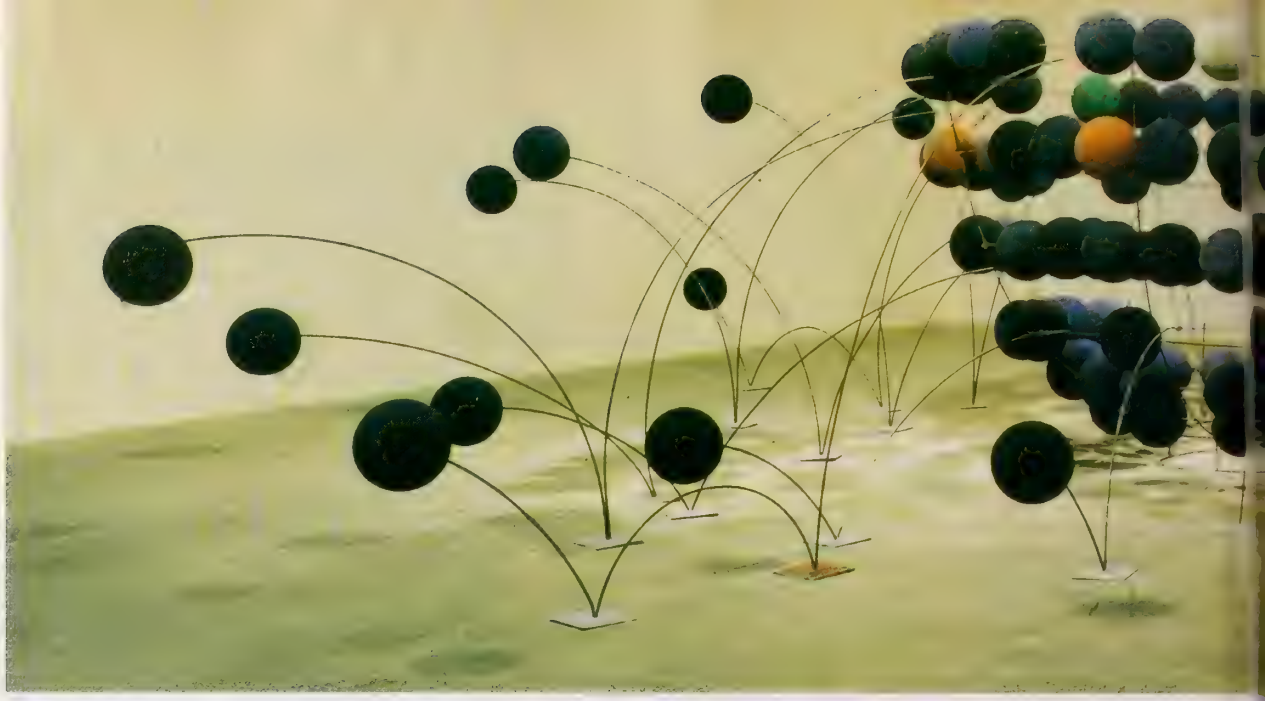
The next step for us is to go beyond the bones. If we could look at sediments in which tetrapods were preserved along with other contemporary plants and animals, we could put tetrapods in their ecological context. A chance to do just that emerged in a Pennsylvania site known as Red Hill. It has yielded several fragments belonging to at least three distinct tetrapod species. The surrounding sediments showed that the climate was warm and subtropical, yet seasonally variable. The Red Hill tetrapods lived in a river basin surrounded by diverse flora and fauna.

About 385 million years ago, or a little less, dense forests were beginning to grow beside rivers and lakes. The onset of a seasonal climate in the Late Devonian had promoted the evolution of deciduous trees. As they dropped their leaves into the water, bacteria that feasted on their remains used up most of the oxygen in the water. At the same time, oxygen levels in the atmosphere were beginning to rise, and so any creature that was more effective than other animals at breathing air would have had an advantage.

Invertebrates such as millipedes, mites, scorpions, and primitive wingless insects had crawled onto land and filled an array of damp, green habitats. They had also gotten bigger and become potential sources of food for four-footed predators. Once true limbs evolved, tetrapods were better able to exploit areas of densely vegetated shallow water and swamp that fish with fins could not.

In the past twenty years, discoveries have radically changed what we paleontologists think about the origin of four-legged animals. Important finds have altered what we thought we knew about the gradual transition from water to land, as some pieces of the puzzle have been moved about and others added. With *Tiktaalik*, an intermediate stage between finned *Eusthenopteron* and footed *Ichthyostega* has come into focus. *Acanthostega* and *Ichthyostega* have revealed their bone structures, modes of moving, and lifestyles. The Red Hill fossils have provided an ecological context. More exploration will only make the story richer. The same holds for the knowledge of how tetrapods diversified and spread out. The early ones traveled quickly on their four feet. From one point of origin, they soon fanned out into far-flung parts of the Late Devonian world and adaptively made themselves at home—on land, on feet. The rest is evolutionary history. □

*Right hind limb of* Ichthyostega, measuring six inches long, *could not have borne its share of the animal's weight. It is paddlelike and shows no real knee or ankle joint. The triangular bone at the top of the fossil is the pelvis.*



# Beyond the Big Bang

*A new cosmic worldview holds that countless replicas of Earth, inhabited by our clones, are scattered throughout the cosmos.*

By Alex Vilenkin

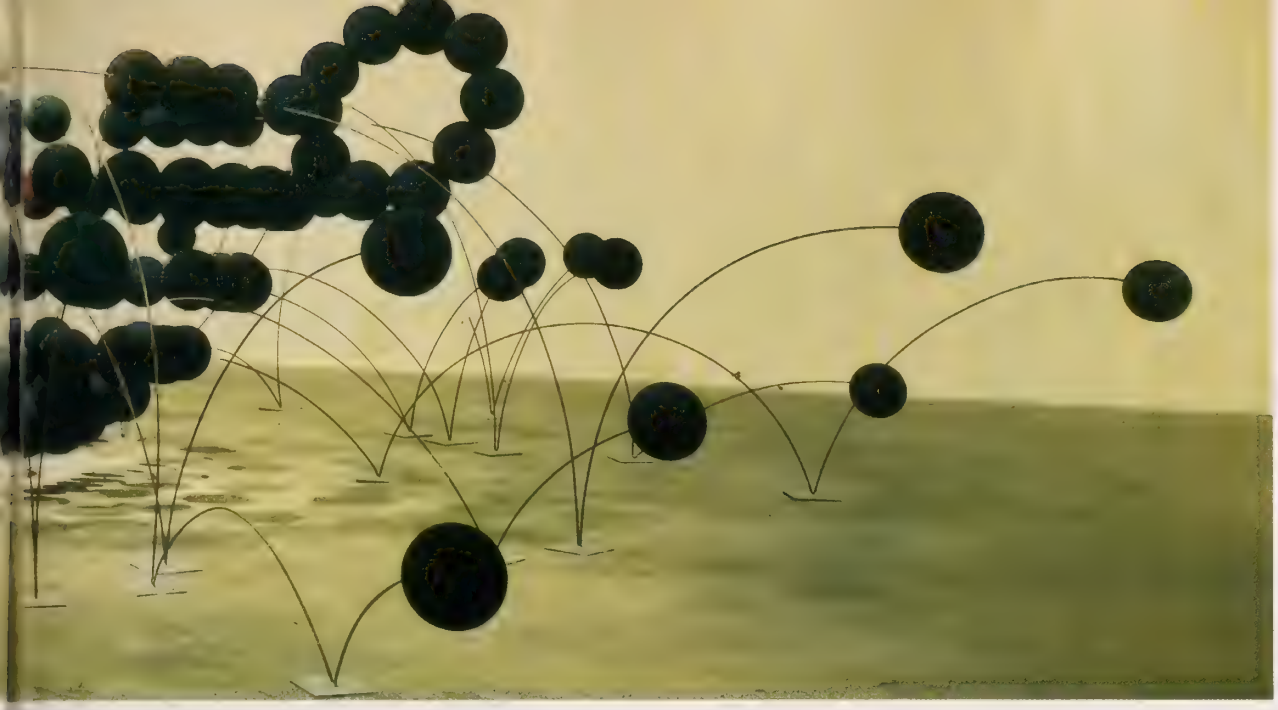
We all live in the aftermath of a great explosion. This awesome event, somewhat frivolously called the big bang, took place some 14 billion years ago. We can actually see some of the cosmic history unfolding before us since that moment—light from remote galaxies takes billions of years to reach our telescopes on earth, so we can see galaxies as they were in their youth. But there is a limit to how far we can see into space. Our horizon is set by the maximum distance light could have traveled since the big bang. Sources more distant than that horizon cannot be observed, simply because their light has not yet had time to reach Earth.

But if there are parts of the universe we cannot detect, who can resist wondering what they look like? Do they simply harbor more stars, more galaxies, more of the same—or could it be that distant parts of the universe differ dramatically from our cosmic neighborhood? Does the universe extend to infinity, or does it close in on itself, like the surface of the Earth?

As they address these provocative yet fundamental questions, cosmologists can rely only on indirect, circumstantial evidence, using measurements made in the accessible part of the universe to make inferences about the places that cannot be observed. That limitation makes it much harder to prove one's case "beyond a reasonable doubt." But because of remarkable recent developments in cosmology, some of the ultimate cosmic questions now have answers that we have some reason to believe.

The emerging cosmic worldview combines, in surprising ways, some seemingly contradictory features: the universe is both infinite and finite, evolving and stationary. That view of the universe also holds that in some remote regions there are planets exactly like our Earth, with continents of the same outline and terrain, inhabited by identical creatures, some of them holding copies of this magazine in their hands.

The core of the new cosmological paradigm is "eternal inflation," a subject of my research that grew out of the theory of inflation first put forward in 1980 by Alan Guth, a physicist at the Massachusetts Institute of Technology. Guth suggested that the early universe contained some highly unusual mate-



Dennis Oppenheim, *Image Dissonance—Coffee Cup*, 1988–89

rial that created a strong repulsive gravitational force. That special material is known as the false vacuum, and according to Guth, it blew the universe up.

A vacuum is empty space—space devoid of all material particles. It is often regarded as synonymous with nothing. But according to modern theories of elementary particles, a vacuum is a physical object; it can be charged with energy and can come in different states. We live in the lowest-energy vacuum, the so-called true vacuum (familiar empty space). High-energy vacuums are called false because, unlike the true vacuum, they are unstable. The most remarkable property of a false vacuum is its repulsive gravity. According to Einstein, if a vacuum has energy, it should also have tension, which has a repulsive gravitational effect. The repulsion due to vacuum tension turns out to be three times stronger than the attractive gravity of the vacuum energy (which is related to mass via Einstein's formula $E=mc^2$). The net effect is a strong repulsive force.

Guth considered what would happen if, at some early epoch, the entire universe were in a false-vacuum state. He found that the repulsive gravity of the vacuum would cause the universe to expand exponentially—or, in other words, by a constant factor for each constant interval of time. Exponential growth can be characterized by the doubling time, or the time it takes for a given quantity to double in size. (The doubling time for $100 invested at 6 percent annual interest, for instance, is about twelve years, so that at the end of twenty-four years the $100 investment is worth about $400.)

For the expansion of a universe permeated by a false vacuum, the doubling time is unbelievably short. It depends on the energy density (measured in units of energy per cubic centimeter) of the particular kind of false vacuum, but it never exceeds one ten-billionth of a second. A straightforward calculation shows that the universe would expand by a factor of a googol ($10^{100}$) in less than one-thirtieth of a microsecond.

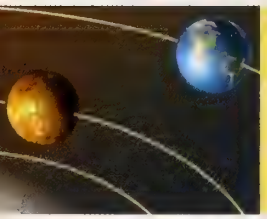
Since a false vacuum is unstable, it eventually decays, turning into the true vacuum. In so doing, its prodigious energy ignites a hot fireball of elementary particles. That event signals the end of inflation and the starting point of the usual cosmological evolution. It plays the role of the big bang in Guth's cosmology. Thus an enormous, hot, expanding universe emerges from a tiny initial seed.

The theory of inflation was little more than a speculative hypothesis when Guth proposed it, but it was soon enhanced and developed by the work of many physicists, most notably Andrei Linde of Stanford University. Moreover, in the late 1990s, observations of distant supernovae and of the cosmic microwave background radiation—a faint afterglow of the big bang—gave the theory an enormous boost of corroborating observational evidence. So today, inflation is well on its way to becoming one of the cornerstones of modern cosmology.

In a way, inflation caused by a false vacuum is similar to the reproduction of bacteria. In both cases, two processes compete for dominance: bacteria reproduce by division, but occasionally they are also destroyed by antibodies. The outcome depends on which process is more efficient. If the bacteria reproduce faster than they are destroyed,

they multiply rapidly. If destruction is faster, the bacteria quickly die out.

With inflation, the two competing processes are the decay of the false vacuum and its "reproduction," because the inflating regions are expanding rapidly. Roughly speaking, the false vacuum decays because of random quantum mechanical fluctuations in the energy density of the vacuum. So to estimate which process would win, I analyzed how the effects of quantum fluctuations compared to the rate of inflation. My analysis showed that false-vacuum regions multiply much faster than they decay. In other words, even though the false vacuum is constantly decaying, inflation proceeds so rapidly that there is no way to stamp out the false vacuum everywhere in the universe at once.



***Many other big bangs went off before ours did, in remote parts of the universe.***

That result has extraordinary implications. In vast reaches of the universe, the ever-expanding wildfire that is inflation will never end; the volume of the inflating regions will keep growing forever, without bound. At this very moment, some distant parts of the universe are filled with false vacuum and are undergoing exponential inflationary expansion. Regions like ours, where inflation has ended, are also constantly being produced. They form "island universes" in the inflating sea of false vacuum. Because of inflation, the space between the island universes rapidly expands, making room for more island universes to form. Thus inflation is a runaway process that has stopped in our neighborhood but still continues in other parts of the universe, causing them to expand at a furious rate and constantly spawning new island universes like our own.

Because the decay of the false vacuum and ensuing fireball occur repeatedly, the big bang loses its central status as a one-time event in the history of the universe. "Our" big bang gave rise to the stars and the galaxies we can see, as well as to many objects beyond our visible horizon. But many other big bangs went off before ours did, in remote parts of the universe, and countless others will erupt elsewhere in the future.

If cosmologists could somehow observe the inflating universe from the outside, just as the surface of the Earth can be observed from space, they would see a multitude of island universes (regions of true vacuum) scattered in the vast inflating sea. If the entire universe is shaped like the three-dimensional analog of the surface of a sphere, the view that would open in front of them might resemble a globe, with continents and archipelagoes surrounded by ocean. The "globe" is expanding without bound at a staggering rate, the island universes are also growing exceedingly fast, and tiny new islands are constantly appearing and immediately starting to expand [*see illustration on opposite page*].

The inhabitants of island universes, like us, see a different picture. They do not perceive their universe as a finite island. For them it appears as a self-contained, infinite universe. That dramatic difference in perspective is a consequence of the differences imposed by the ways of keeping time appropriate to the global and internal views of the island universe. (According to Einstein's theory of relativity, time is not fixed, but depends instead on the observer.)

When cosmologists talk about a "moment in time," they picture a large number of observers, equipped with clocks and scattered throughout the universe. Each observer sees a small patch of the universe, but the whole assembly is needed to describe a large region.

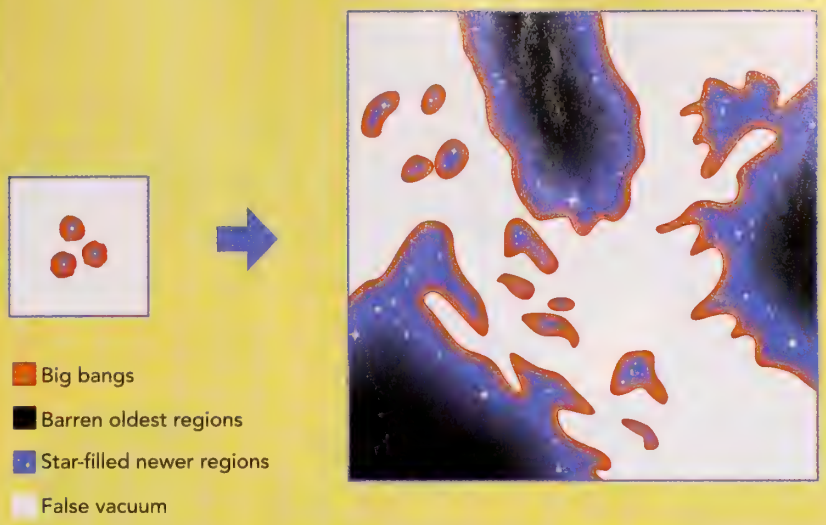
In the global view, the definition of a "moment of time" is largely arbitrary, because there is no obvious way to synchronize the clocks of observers across the false vacuum and in different island universes. The number and the shape of the islands may differ, depending on this choice of definition. By contrast, to describe one specific island universe from the point of view of its inhabitants, there is a natural rather than arbitrary choice for the origin of time. All observers inhabiting the island universe can count time from the big bang at their respective locations. Their big bang is thus set as time zero in their entire island universe. Remarkably, from such an internal viewpoint the island universe is infinite.

Perhaps the easiest way to see this is to count galaxies. In the global view, new galaxies are continually formed near the expanding boundaries, so as time passes, the number of galaxies grows without bound. In the internal view, all those galaxies exist simultaneously (say, at time 14 billion years).

The surprising feature of island universes—that they are infinite when viewed from the inside—led me to what is perhaps the most striking consequence of eternal inflation. The analysis goes like this. Since each island universe is infinite from the viewpoint of its inhabitants, it can be divided into an infinite number of regions having the same size as our own observable region. My collaborator Jaume Garriga of the University of Barcelona and I

call them O-regions for short. As it happens, the most distant objects visible from Earth are about 40 billion light-years away, so the diameter of our own O-region is twice that number.

This fact might seem to imply that radiation from those distant objects left for our Milky Way before the big bang, about 14 billion years ago. But actually, shortly after the big bang, the initial separation velocity between the matter that would become our Milky Way and the source of the radiation was enormous, far greater than the speed of light. Points in different parts of the universe can separate from each other at speeds faster than light, because Einstein's ban on such speeds does not apply to geometric entities with neither mass nor energy. Today, whatever was the source of the radiation 14 billion years ago has moved to 40 billion light-years away.




*Island universes condensing out of a region of the inflating "master" universe are depicted schematically at two successive times, one (left) earlier than the other (right), as they might appear if they could somehow be observed from the "outside." Existing island universes enlarge and new ones form as the false vacuum decays, giving rise to big bangs at the peripheries of the islands and at random places amid the inflating sea. The hot, dense matter created in the big bangs coalesces into stars and galaxies, while central parts of the large islands are extremely old, and thus dark and barren. At the same time, the sea of false vacuum expands even faster than the islands do, making room for new islands to form. The diagram is based on a computer simulation.*

Imagine, then, an infinite island universe packed with gigantic spheres, each 80 billion light-years in diameter. Each sphere is an O-region. The spheres expand with the expansion of the universe; the O-regions were smaller at earlier times. All the O-regions looked pretty much the same at the time of the big bang, or in other words, at the end of inflation. But they were different in detail. Small perturbations in density, brought about by random quantum mechanical fluctuations during inflation, differed from one region to another.

As the perturbations were amplified by gravity, the macroscopic properties of O-regions began to diverge. By the time of galaxy formation, the details of how galaxies were distributed from one O-region to another varied considerably—though statistically the regions were still highly similar. Later on, the evolution of life and intelligence was influenced by chance, leading to further divergence of properties among the O-regions. The histories of distinct O-regions should thus be rather different.

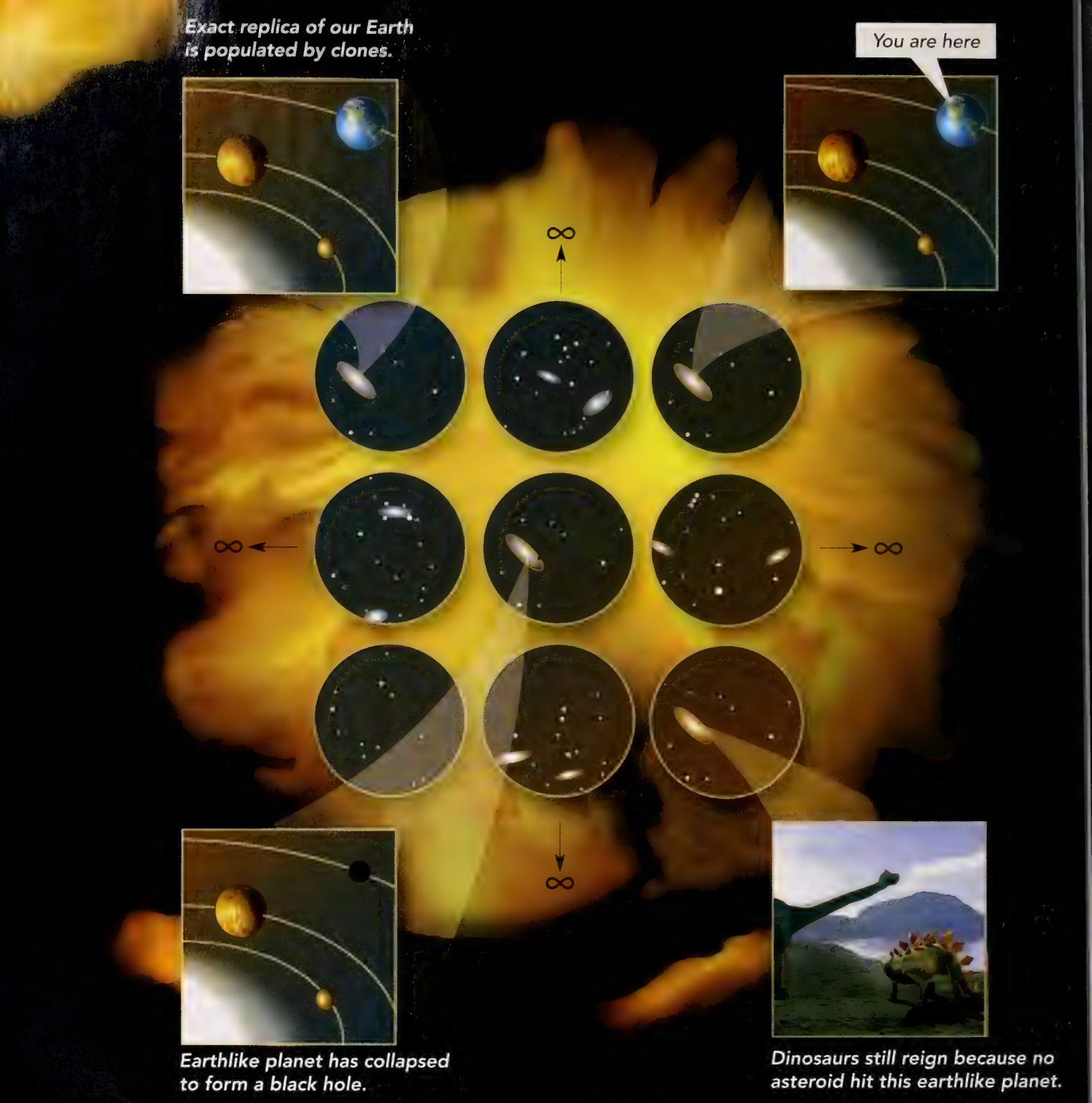
The key observation was that the number of distinct configurations of matter that can possibly be realized in any O-region—or, for that matter, in any finite system—is finite. One might think that arbitrarily small changes could be made in the system, thus creating an infinite number of possibilities. But that is not the case.

If I move my chair by one centimeter, I change the state of our own O-region. I could instead move it by 0.9 centimeter, 0.99 centimeter, 0.999 centimeter, and so forth—an infinite sequence of possible displacements, which more and more closely approach the limit of one centimeter. There is a problem, though. Displacements too close to one another cannot be distinguished, even in principle, because of quantum mechanical uncertainty.

In classical, Newtonian physics, the state of a physical system can be described by specifying the positions and velocities of all its constituent particles. But because of the underlying reality of quantum mechanics, such a description can apply only to massive, macroscopic objects, and even then, only approximately. In the quantum world, particles are inherently fuzzy and cannot be localized precisely.

Since the precise positions of particles cannot be pinned down, one can resort instead to a so-called coarse-grained description. Suppose the volume of our O-region is divided into cubic cells of a certain size, say one cubic centimeter each. You can specify a coarse-grained physical state by indicating the cell occupied by each particle in the region. To make a more refined description, you just make the cells smaller, say, a cubic nanometer. But this kind of refinement has its limits, because there is a quantum mechanical energy cost of localizing particles to small cells. That cost will eventually exceed the available energy in the O-region.

Evidently, the number of ways a finite number of particles can be distributed into a finite number of cells is also finite. Hence the material content of our O-region can take on only a finite number of distinct states. A very rough estimate of this number gives 10 to the power $10^{90}$, or 1 followed by $10^{90}$ zeros. This number is fantastically huge, too




*Island universe in which we live encompasses infinitely many observable regions, or "O-regions," each the size of our observable universe. Each sphere in the schematic diagram represents a region whose radius is equal to the distance from Earth to the most distant objects we can see: about 40 billion light-years. The Earth lies inside one such O-region. Because of the "graininess" of space and time in quantum mechanics, the number of possible histories of all the particles inside such a region, beginning with some fixed moment in the past, is finite (though, of course, huge). Since the number of O-regions is infinite, every possible history—a world in which Earth collapses to form a black hole, for instance, or a world in which the dinosaurs still survive—is replayed in an infinite number of O-regions, the closest ones at least a googolplex (10 to the power $10^{100}$) light-years away. The O-regions are all shown at the same time after the big bang, which corresponds to an "internal view" of the island universe. The internal view is used only to portray the O-regions that make up part of the interior of one island; the other islands would not be visible in a consistent diagram, but in the "global view" that has been overlaid on this drawing, several other island universes appear.*

big even to be written down in standard notation with digits of ordinary size on paper that could be fitted into the part of the universe we can observe. But the important point is that the number is finite.

Not only is the number of possible states of an O-region finite; the number of its possible histories is finite as well. A history is described by a sequence of states at successive moments of time. Which histories are possible in quantum physics differ immensely from the ones possible in the classical world. In the quantum world the same initial state can lead to a multitude of outcomes to which only probabilities can be assigned. Consequently, the range of possible histories is greatly enlarged.

Once again, though, the fuzziness imposed by quantum uncertainty makes it impossible to distinguish histories that are too close to each other. The histories of various O-regions can be distinguished only if the successive moments in the histories are separated by sufficiently large (though still tiny) intervals of time. Giving such a coarse-grained history is much like recording a movie in a digital format: you simply specify the cell "addresses" for all the particles in the O-region at each moment in the finite sequence of intervals. Any finite number of states, each specified for a finite number of moments, yields only a finite number of distinct histories of the system.

Garriga and I did a quick, back-of-the-envelope estimate of the number of possible histories that can unfold in an O-region between the big bang and the present. As one might expect, we got yet another "googolplexic" number: 10 to the power $10^{150}$ (a googolplex is 10 to the power of a googol). The actual numbers of the quantum states and of possible histories in an O-region are not particularly important, but the fact that those numbers are finite has far-reaching implications, indeed.

It may be helpful to take stock of the cosmic story so far. It follows from the theory of inflation that island universes are internally infinite, so that each of them comprises an infinite number of O-regions. And it follows from quantum uncertainty that only a finite number of histories can unfold in any O-region. Putting those two statements together, it follows that every single possible history should be repeated an infinite number of times within any of the island universes—including, of course, the one we inhabit. In quantum mechanics, anything not strictly forbidden by the conservation laws of physics must happen—and has happened—in an infinite number of O-regions.

Among the infinitely replayed scripts are some very bizarre histories. For example, a planet similar to our Earth can suddenly collapse to form a black hole. Such an event is extremely unlikely, but all that means is that, before encountering it, one would, in all probability, have to survey an enormous number of O-regions within our island universe.

A striking consequence of the new picture of the world is that among the infinite number of O-regions is an infinite subset of those regions with histories absolutely identical to ours. Yes, dear reader, scores of your duplicates are now reading copies of this article. They live on planets exactly like Earth, with all its mountains, cities, trees, and butterflies.

How far away are these earths populated by our clones? Matter in our O-region can assume about 10 to the $10^{90}$ distinct states. A box large enough to hold, say, a googolplex O-regions should exhaust all those possibilities by a large margin. Such a box would be roughly a googolplex light-years across. At greater distances, O-regions, including ours, should recur. There should also be regions whose histories differ from ours, with all possible variations. They all belong to the same spacetime, and given enough time, our descendants might, in principle, be able to visit the inhabitants of another O-region.

*With humankind reduced to absolute cosmic insignificance, our descent from the center of the world is now complete.*

But we will never be able to reach another one of the island universes (each with its own infinite complement of O-regions), or even send a message there. The reason is that no one will be able to keep up with the boundaries of the island universe, which are expanding faster than the speed of light. Thus, we will never be able to reach the shores of the inflating sea and bask in the light of the new suns that will be born there. We cannot even proclaim our own existence to the future civilizations that will thrive around these suns.

Regardless of their accessibility, other universes and other O-regions will surely change our larger sense of place. In the worldview that has emerged from the ideas of eternal inflation, our civilization is anything but unique. Instead, countless identical civilizations are scattered across the cosmos. With humankind reduced to absolute cosmic insignificance, our descent from the center of the world, a process begun by Copernicus (in this world and on countless others) is now complete. □

*This article was adapted from* Many Worlds in One: The Search for Other Universes, *by Alex Vilenkin, which is being published in July by Hill and Wang.*

By Laurence A. Marschall

# Science Most Foul

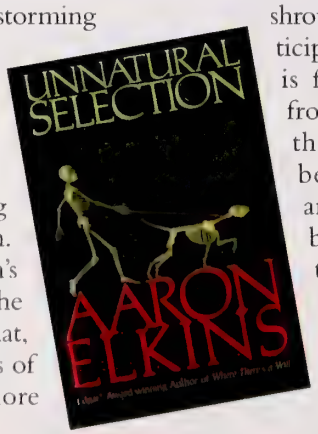
*Summertime, and the reading is easy. You don't escape to the beach or the mountains to fritter away your lazy hours fretting about the pollution of the Arctic or the effects of invasive species on Hawaiian biodiversity. No, what you want is a healthy homicide. It's best if the crime is outrageous, the suspects menacing, and the investigator both noble and quirky. Still, there's no reason not to mix in a little science with the mayhem. After all, wasn't Sherlock Holmes a master chemist, and Watson a trained physician?*

*Everyone has perennial choices, I'm sure. High on my list would be almost any novel by Nevada Barr, whose crime-stopping park ranger Anna Pigeon seems to have worked at most of the great scenic wonders of North America. Less well known, but equally entertaining, is Morgan O'Brien, the creation of the Canadian novelist Alex Brett. O'Brien may be one of the few detectives whose specialty is scientific-research fraud, and her latest adventure,* Cold Dark Matter *(2005), authentically set in a large mountaintop observatory, involves murder, mayhem, and, not incidentally, spectroscopy of distant galaxies.*

*Thankfully, there seems to be no shortage of writers who can artfully blend mystery and science. Among the most enjoyable new publications that have graced my nightstand in recent months are these prime candidates for summer fun:*

***Unnatural Selection*** *by Aaron Elkins (Berkley Books; $23.95)*

Gideon Oliver, forensic anthropologist extraordinaire, makes his thirteenth appearance in this latest novel by Edgar Award–winner Aaron Elkins. The setting is pure Agatha Christie: a brooding castle in the Isles of Scilly, off the Cornish coast of England, where a small group of environmental experts—including Gideon's spouse, Julie, an expert on wildfire management—have assembled for a weeklong brainstorming session hosted by an eccentric Russian entrepreneur. While Julie deals with the inflammable mix of personalities at the daily colloquia, Gideon kills time examining artifacts at the local museum. Mixed in with the museum's prehistoric skeletal remains, he discovers, is a human bone that, to his trained eye, shows signs of murder most foul. Soon more bones show up on a local beach, and it becomes clear that they all belong to the victim of a brutal dismemberment that took place a bit more recently than the Bronze Age. There is no record, however, of any local person gone missing. So whose bones are they?




As Gideon ponders the evidence and the local police chief investigates, the fog rolls in and the fog rolls out. Tempers flare and passions simmer among the invitees at the castle. Then, one mist-shrouded midnight, a participant in the workshop is forcibly precipitated from a parapet. Could there be a connection between this murder and the dismembered bones? Well, of course there is, but you must resist the temptation to leapfrog to the obligatory scene in which all the assembled suspects find out which of them is guilty. The pleasure of summer reading lies not in resolution but in investigation, and Elkins keeps things moving with plenty of local atmosphere, compelling characterization, and a refreshingly low level of violence. *CSI: Miami* it's not, but it would make a lovely episode on the BBC *Mystery Monday* series.

***The Darwin Conspiracy*** *by John Darnton (Alfred A. Knopf; $24.95)*

After five vigorous years aboard the H.M.S. *Beagle*, Charles Darwin returned to England a broken man. His mind was sharper than ever, to be sure, and many decades of groundbreaking research and writing lay ahead, but his body was already beginning to fail. For the rest of his life he complained of nausea, vomiting, flatulence, skin rashes, headaches, vertigo, and countless other maladies. For all of them he sought remedies that, given the primitive state of medicine at the time, may have done him more harm than good. At various times Darwin dosed himself with opium, shocked himself with electricity, and wrapped his body with towels soaked in freezing water—all to no avail.

Darwin's illness is a real historical mystery: How could a young man who galloped on horseback over the Pampas and backpacked (sans Gore-Tex) in the Andes, turn so prematurely into an elderly invalid, obsessed with rampant bodily dysfunctions?

To the shelf of scholarly monographs addressing this question, vacation readers should welcome *The Darwin Conspiracy,* a fast-paced novel of romance and intellectual intrigue by John Darnton, who was editor and foreign correspondent for *The New York Times.* Its protagonists are Hugh Kellem, an anthropologist, and Beth Dulcimer, an evolutionary biologist, whose pursuit of the Darwinian lore—and of each other—begins on a remote island of the Galápagos, amidst the finches that helped inspire the theory of natural selection.

The two return to England and become fascinated with the hidden threads

of Darwin's life, aided by the fortuitous discovery of a series of journals written by Darwin's daughter Lizzie. There are a few side plots, and numerous flashbacks re-creating Darwin's travels on the *Beagle,* but most of the detective work here is of the academic sort, carried out in dimly-lit archives, vaguely suggestive of *The Da Vinci Code,* but nowhere near as ominous.

If you're a Darwin buff, you may find much of Darnton's narrative familiar, since he has scrupulously mined information from Darwin's journals and letters as well as from the many Darwin biographies written over the years. But the writing is snappy and smart, and the final diagnosis of Darwin's debility is so audacious and amusing that even the most jaded summer reader will regard the few hours unraveling *The Darwin Conspiracy* as time well spent.

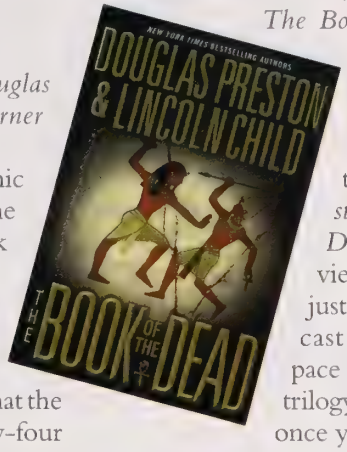
***The Book of the Dead*** *by Douglas Preston and Lincoln Child (Warner Books; $25.95)*

Most of the action of this gothic tale of Gotham takes place in the remote galleries of the "New York Museum," a thin disguise for the American Museum of Natural History at Central Park West and Seventy-ninth Street. But that's plenty of real estate, considering that the fictional museum includes thirty-four interconnected buildings with more than 2 million square feet of space and more than eighteen miles of corridors. Most of the collection has never been seen by the public, including (according to Douglas Preston and Lincoln Child) the Tomb of Senef, a colossal Egyptian monument imported stone by stone in the 1800s, but sealed off for more than three-quarters of a century.

Archaeologist Nora Kelly is in charge of renovating the tomb for a new exhibition, partly to burnish the reputation of the museum, which has been shaken by a recent murder and the theft of its entire diamond collection by archfiend Diogenes Pendergast. But there is much more bloodshed to come, as the master criminal unfolds his plan to terrorize the rich and powerful of New York City at the official opening of the new exhibition. Only one man can stop the impending catastrophe: Diogenes' older brother, F.B.I. Special Agent Aloysius X.L. Pendergast. Alas, Aloysius is locked up in a federal maximum security cell, framed for a murder his brother committed. Is all hope lost?

Not to worry. Agent Pendergast, whose crime-fighting skill makes Sherlock Holmes look like Inspector Clouseau, has his own plan. With the help of a group of lower Manhattan irregulars, he busts out of stir just in time to stop the massacre of the innocents and to track down his evil sibling.

I doubt I've given too much away. Agent Pendergast and his crew have appeared in several best-selling novels by Preston and Child, and by the time *The Book of the Dead* opens, he's already pursued the incorrigible Diogenes through *Brimstone* and *Dance of Death.* A short review can hardly do justice to the large cast and relentless pace of action of the trilogy, but be warned, once you start reading, it will be hard to stop. The characterization never rises above the level of caricature, to be sure, and the plotting is never less than over-the-top. But isn't that reason enough to put it on your summer list?




***The Oxygen Murder*** *by Camille Minichino (St. Martin's Minotaur; $24.95)*

Not many murder mysteries are illustrated by diagrams of inorganic molecules, but that seems entirely appropriate if the crime involves Gloria Lamerino, a retired Berkeley physicist currently



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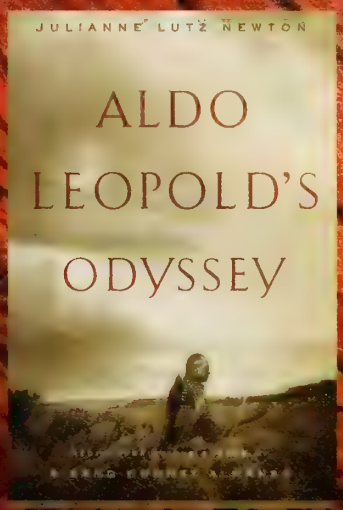


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—Aldo Leopold

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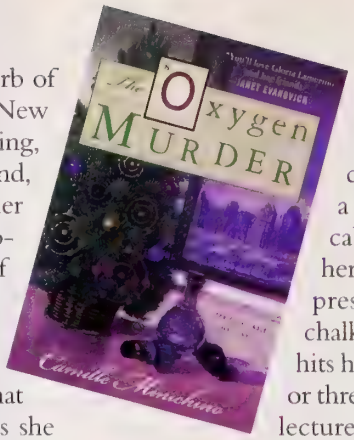
residing in the north Boston suburb of Revere. This time around, she's in New York City, doing Christmas shopping, enjoying the cuisine of Little Italy, and, incidentally, trying to find the killer of a cinematographer found suffocated in the midtown apartment of her husband's niece. The niece, it turns out, is making a documentary about ozone ($O_3$) pollution in the workplace, and it could be that one of the business establishments she was spotlighting took drastic measures to conceal their violations of environmental law. Then again, it could have been one of the people her cinematographer was blackmailing.




At first read, Lamerino seems more like an Italian grandmother than a hard-nosed detective. She's a reluctant investigator, driven mostly by curiosity and the need to do something with her brain now that she's no longer in the lab. Afraid of guns, she even worries herself into a tizzy when she pilfers an incriminating document from a suspect's filing cabinet. But give her a PowerPoint presentation or a chalkboard, and she hits her stride. Two- or three-page science lectures immediately come forth, such as how CFCs harm the ozone layers, that read as if they were lifted from a textbook. And, pushed into action, she's sharp-eyed and resourceful, and she always seems to come through her inevitable encounters with perps suffering only minor injuries.

That's fortunate, because Lamerino has a remarkable proclivity for encountering crimes. She's solved seven "element" murders before this one, starting from the top of the periodic table: hydrogen, helium, lithium, beryllium, boron (well, actually, boric acid), carbon, and nitrogen.

The pattern was no doubt inspired by Sue Grafton, whose "Alphabet" series, featuring detective Kinsey Millhone, is up to "S" *(S is for Silence)*. But if Camille Minichino's pattern continues, she'll be writing a lot longer than Grafton will, since the number of naturally occurring chemical elements (ninety-two) is a good deal greater than the number of letters in the alphabet. If Minichino, like Gloria Lamerino, is looking forward to an easy and crime-free retirement, she's out of luck—which is very good news for summer readers.

**Also Worthy of Mention:**
*Intuition* by *Allegra Goodman (The Dial Press; $25.00)*

Like Goodman's earlier books, *Intuition* is a literate and perceptive exploration of human relations, not a pure entertainment. It's set in a lab in Cambridge, Massachusetts, where a young postdoc is embroiled in a controversy over falsifying data. There's mystery and conflict, along with a sharply drawn cast of characters, just as in the genre mysteries. But this is a lovely book that readers will find not a guilty pleasure, but a pure delight.

*Quarry* by *Susan Cummins Miller (Texas Tech University Press; $24.95)*

The geologist heroine is just about to defend her thesis, when one of her doctoral examiners is murdered. And that's just the start of this fast-moving and authentic thriller that effectively conveys the feel of geological fieldwork along with its high-adrenaline plot line. Geologist MacFarlane is making her third outing here, and she clearly ranks among the upper strata of scientifically trained detectives.

*Laurence A. Marschall, author of* The Supernova Story, *is W.K.T. Sahm Professor of Physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

## LETTERS

*(Continued from page 10)*

the atmosphere, as much as all the cars and light trucks in the United States."

The Centralia, Pennsylvania, mine fires have been burning since 1962. The Jaharia mine fires in India have been burning since 1916. The contribution of those fires to global emissions of carbon dioxide should be a part of any thoughtful discussion on climate change.

*David Hutchins*
*Ocean Ridge, Florida*

I applaud your printing of Jeff Goodell's "Commentary" and especially your giving it the cover priority it deserves. In the many years I have read your publication, *Natural History* has displayed consistently first-class journalism. With this article, however, you are taking a bold step and a desperately needed stand on the major issue of this century: climate change and other environmental disasters. I say this sadly, because those of us involved in these issues know how radically the

*(Continued on page 52)*

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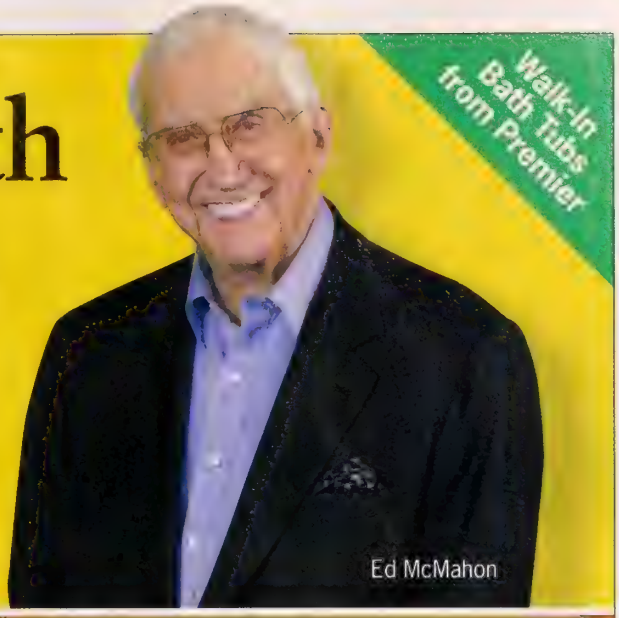

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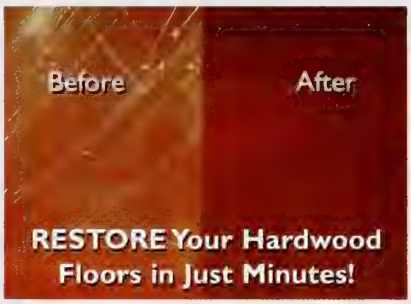


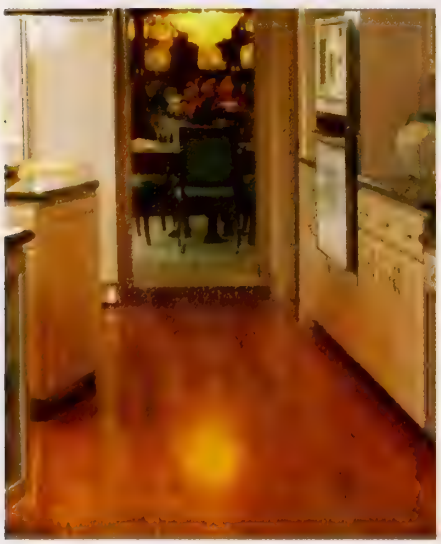

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## LETTERS

human race must refocus and rethink its priorities.
*Jon Deak*
*New York, NY*

Jeff Goodell's article was based on minimal facts and pseudoscience, and I was shocked that you would publish it. I am a geologist and know of the lack of correlation between climate and carbon dioxide. I am also involved with mining, so am aware of the fanciful descriptions Goodell had of mountaintop mining. The errors in his article are easily spotted: 1,000-foot-thick surface mines, 400,000 acres of forest lost, and 700 miles of streams destroyed.
*Ken Fishel*
*Lexington, Kentucky*

JEFF GOODELL REPLIES: The 400,000 acres of forest lost and 700 miles of streams destroyed, data that Ken Fishel dismisses as erroneous, are well-documented in an exhaustive report on mountaintop mining issued by the U.S. Environmental Protection Agency in October 2005. As for the "1,000-foot-thick surface mines," the photo caption simply describes how workers "blast away the uppermost 800 to 1,000 feet of rock to expose layers of coal within." The truth of this is apparent to anyone who glances at a photograph of a big surface mine, much less has been personally involved in the mining industry.

Finally, as for the "lack of correlation between climate and carbon dioxide," I presume Mr. Fishel grasps the basic physics of the greenhouse effect, and that what he really is talking about is the *complexity* of the correlation between climate change and carbon dioxide—a subject that was, alas, beyond the scope of my brief article about coal.

Natural History *welcomes correspondence from readers. Letters should be sent via e-mail to* nhmag@naturalhistorymag.com *or by fax to 646-356-6511. All letters should include a daytime telephone number, and all letters may be edited for length and clarity.*

# Reptilophilia

*By Robert Anderson*

I've never been much for pets—too much responsibility. Once, though, when a herpetologist friend offered me a turtle that had been turned over to him by customs agents, I said yes. A victim of the illegal pet trade, it was a big-headed turtle (*Platysternon megacephalum*, similar in appearance to New World snappers) that had flown in from the wilds of Southeast Asia to New York City before it was confiscated. My turtle was an admirable beast with a powerful, hooked beak to crack open crustaceans and mollusks. He was also adept at stalking small fish. "Jaws"—I guess the name was inevitable—taught me that, in the end, turtles can be lightning fast (you can see photographs of his species at the turtle site chelonia.org/platysternon_gallery.htm).

Jaws gave me an appreciation for turtles, and for reptiles in general, a group with more than 8,000 known living species. Go to the Reptile Database at the European Molecular Biology Laboratory in Heidelberg, Germany (www.embl-heidelberg.de/~uetz/LivingReptiles.html) and click on "How many species?" for a breakdown of the clan and a link to a map showing its global distribution. Nearly a quarter of all reptile species are harmless colubrid serpents, which include garter snakes. The second greatest number of species are the skinks, followed by the geckos. The only two surviving species of an entire reptilian order, the tuataras, live on islands off the coast of New Zealand. Both are endangered, and climate change may finish them off (news.bbc.co.uk/1/hi/sci/tech/1896463.stm). The Center for North American Herpetology (cnah.org) has links to comments on the taxonomy and photos of local species.

Although reptiles are popular as pets and in zoos, real enthusiasts enjoy spotting them in the wild. At the Web site of Mike Pingleton, an amateur herpetologist (pingleton.com), click on "Notes from the Field" to read about his adventures tracking down hundreds of species of frogs, lizards, snakes, and turtles. Another intriguing site (flyingsnake.org) may not be for everyone, particularly if serpents give you the willies. Movie clips document how certain Southeast Asian tree snakes propel themselves through the air, gliding from branch to branch [*see "Serpents in the Air," by Adam Summers, May 2003*].

You can learn a lot about human biology from the differences and similarities between reptiles and mammals. What are the advantages of being hot- or cold-blooded? Go to NASA's "Infrared Zoo" (coolcosmos.ipac.caltech.edu/image_galleries/ir_zoo/coldwarm.html) for an illustrated discussion of the various approaches to regulating body temperature.

Thermal regulation and other differences aside, human beings share much with reptiles. Unlike amphibians, which must remain in water to reproduce, reptiles were the first animals to have eggs with an amniotic sac, which enabled them to fully conquer land. At the Tree of Life Web site (tolweb.org/Amniota), you can read more about how reptiles paved the way for later vertebrates. Dinosaurs, birds, and mammals, all with an amniotic sac, are all descendants of early reptiles.

Another bit of anatomy people inherited from reptiles is the core of the brain. At the Web site of the Canadian Institute of Neurosciences, Mental Health and Addiction (www.thebrain.mcgill.ca) is a brief description of the "three" human brains: the reptilian brain, the limbic brain, and the neocortex. An interactive diagram at www.brainchannels.com/evolution/physicalbrain.html#Anchorreptilian gives more detail. Some mental-health problems are rooted in our reptilian brains (www.psychoeducation.org/emotion/R%20complex.htm), so you may want to blame your obsessive-compulsive disorder . . . on your turtle.

*ROBERT ANDERSON is a freelance science writer living in Los Angeles.*

# Deceptive Nebulous Apparition?

## *The double helix at the center of the galaxy*

By Charles Liu

Appearances can be deceiving—especially in outer space. Thirty years ago, the *Viking 1* orbiter took thousands of photographs of the Martian surface: craters, canyons, mountains, and more. The peaks and shadows of one mountain evoked a fuzzy, mile-wide human face. For the next quarter century, folks with vivid imaginations—including some who were pretty handy with image-enhancing software—insisted that this geological oddity was evidence of intelligent life on Mars. Finally, in 2001, high-resolution images made by the *Mars Global Surveyor* laid their speculations to rest: the first "face" was a coincidental confluence of light and shadow. The mountain was really just a mountain.

But you can't blame people whose eyes led them to an anthropomorphic conclusion. They were far from the first, even among Mars-watchers. A century ago the American astronomer Percival Lowell thought he saw a vast network of artificial canals on the Martian surface, and his sketches and speculations created a sensation.

Such misinterpretations happen all the time, according to psychologists. The human tendency to translate random sensory input into familiar shapes is an important cognitive process. It helped early humans recognize predators and other threats in the environment. It also helps explain why people have given constellations, star clusters, and nebulae the names of gods, humans, animals, and other terrestrial objects.

So it's understandable that today, when genetics and biotechnology loom large in our collective consciousness, astronomers have dubbed one recent discovery the Double Helix Nebula. That object, a coiling jet of glowing gas—spied with an infrared eye by a team of astronomers led by Mark R. Morris of the University of California at Los Angeles—looks a lot like a strand of DNA. This striking corkscrew structure is a mere 200 light-years away from the nucleus of our galaxy, and it may well emanate from that enigmatic middle of the Milky Way—where a gaseous spiral, a disky gaseous ring, a swarm of hot young stars, and a supermassive black hole all lurk behind a deep, dense screen of dusty gas.

Even without a glowing double helix sticking out of it, the galactic center is a weird place. For starters, its black hole, known as Sgr A* (yes, the asterisk is part of the name), weighs in at a hefty 3.5 million times the mass of our Sun. A swirling whirlpool-like disk of hot, ionized gas, complete with spiral arms that sorta-kinda mimic the larger galaxy in which it resides, is centered on the black hole. Beyond this disk lies another thin disk primarily of molecular gas—picture the rings of Saturn, but a lot bigger and even more chaotic. The second, outer disk is about twenty light-years across. Within, among, and above those gaseous structures are surprisingly large numbers of hot, massive stars that are much younger than the stars you'd expect to find near a supermassive black hole.

How does the Double Helix Nebula fit into this picture? Well first, consider how it was found, a good clue to its identity. It was captured with the aid of the Spitzer Space Telescope (SST), which detects infrared light. Infrared, which is invisible to human eyes but detected by human skin as heat, has longer wavelengths than visible light and can penetrate substantially thicker screens of dust than visible light can. That makes the SST an ideal tool for studying the Milky Way's galactic center, whose visible light is almost completely quenched by intervening, obscuring dust.

Morris and his colleagues had been looking for infrared emissions at a wavelength of about twenty-four microns. That's the wavelength at which interstellar dust emits its greatest heat, if it's at a temperature of −240 degrees Fahrenheit. To their surprise, they noticed a pattern that looked a lot like a double helix. Given the temperature of the pattern, it had to be a stream of dusty gas, more than 100 light-years long and about 200 light-years from Sgr A*.

But could the double helix be another face-on-Mars illusion, perhaps created by a chance superposition of glowing gas? Probably not. There's good reason to think the object has a coherent physical structure. For one thing, it wasn't an isolated discovery. Like the discoverers of Pluto's two

newest moons [*see "Sizing Up Pluto," by Charles Liu, May 2006*], Morris and his collaborators looked through astronomical archives to confirm their observations. They found that more than a decade ago the Midcourse Space Experiment (MSX) had detected the glowing strand, which extends some 100 light-years at nearly right angles from the plane of the Milky Way. If you squint really hard at the MSX image, you can just make out the fuzzy outline of a double helix; because MSX didn't have the resolving power of the SST, however, the structure wasn't visible to anyone who didn't already know to look for it.

Fine. The double-helical coil is out there. Now the obvious question: how'd it get there?

Whenever we astronomers see twists and braids, we think right away of two things: rotation and magnetic fields. When an electrically charged celestial object spins, it often generates a magnetic field. Sometimes, cone-shaped magnetic channels lead from the object's north and south poles. If the rotation is rapid and the field is strong, those channels can direct the flow of electrically charged matter. That flow manifests itself in many phenomena—from the gentle cascade of solar wind toward Earth's poles, which produces the northern and southern lights, to the superenergetic outflows of quasars, which can generate more energy in a second than the Sun does in a million years.

Morris and his colleagues suggest that the double helix could be a magnetic "torsional Alfvén wave," generated by a flattened, electrically charged, spinning gaseous structure. The structure could be the disklike ring of molecular gas that encircles Sgr A*. It's about the right size for the job—a little more than twice the width of the double helix—and it spins around the black hole at a more-than-adequate 200,000-plus miles per hour. Dust particles blown upward from the vicinity of the ring would become ionized by ultraviolet radiation; those particles, now electrically charged, would follow along the magnetic field lines that trace the torsional wave. The particles' infrared glow, picked up by the SST, would appear as a delicate, double-helix structure.

There are a few bugs in this picture, though. For one thing, between the bottom of the double helix and the molecular ring around the galactic center is a gap of more than 100 light-years. For another, the double helix doesn't point directly at the ring. Moreover, since there are always two magnetic poles, a second double helix should be protruding downward, perpendicular to the ring in the opposite direction. But there's only one.

Here's another complication. Can a delicate torsional wave persist long enough to form a double helix that keeps its shape through the rough-and-tumble galactic center and continues twisting evenly hundreds of light-years beyond that?

One example of how dynamic things can get comes from a recent study by Angelle M. Tanner of the Jet Propulsion Laboratory in Pasadena and several colleagues (including Morris). Tanner's team showed that the stars within two light-years of Sgr A*—that is, closer to the black hole than to its encircling gaseous ring—appear to orbit in roughly the same orientation. But unlike the nearby molecular gas, they're not arranged in a ring. Tanner says the stars' scattered arrangement suggests they formed elsewhere and were pulled into the neighborhood rather recently; their "migration" may well have disturbed or disrupted a torsional wave.

Another contributor to the dynamism of the galactic center is the unstable nature of the gaseous ring itself; huge amounts of gas continuously flow in and out of it, which could make the structure of its magnetic field too variable to sustain a prolonged torsional wave.

Until investigators do detailed supercomputer simulations, there probably won't be a complete explanation of the Double Helix Nebula. But I wouldn't be surprised if, years from now, its portrait becomes an icon in the gallery of astronomy. Like the face on Mars, it's a striking image. Unlike that face, though, this picture may actually shed light on the mysteries of the cosmos.

*Infrared image of the central region of our galaxy was made by the Spitzer Space Telescope (SST). The detail (top of opposite page) shows the recently discovered Double Helix Nebula, about 100 light-years long; that image was also obtained with the SST, but at a longer infrared wavelength. The origin of the double-helix structure may be a coil-shaped magnetic wave emanating from a flattened, spinning ring of gas near the black hole at the galactic center. Both black hole and ring are hidden from view within the bright white dot near the center of the image above.*

*CHARLES LIU is a professor of astrophysics at the City University of New York and an associate with the American Museum of Natural History.*

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By Joe Rao

Mercury is too dim and too close to the Sun to see until the last few days of July. It passes through inferior conjunction, between the Earth and the Sun, on July 18 and moves into the morning sky. Look for it at the end of the month, low in the east-northeast sky about forty-five minutes before sunrise.

In August this speedy planet makes a fine morning apparition, as it gains altitude and reaches its greatest western elongation on August 7. On that morning it shines at magnitude +0.1 and rises nearly ninety minutes before sunup. During the next two weeks Mercury slowly drops back toward the Sun, but as if to compensate, it grows progressively brighter. On the mornings of the 9th and 10th you'll find Mercury roughly two degrees below brilliant Venus. Then, on the morning of the 20th, Mercury shifts to just a little more than one degree above Saturn. Two mornings later, a slender crescent Moon, less than thirty-six hours from its new phase, appears to hover well above Mercury. By then, Mercury brightens to magnitude −1.4, matching Sirius, the brightest star in the sky. For the rest of the month it disappears into the dawn.

Venus shines brilliantly at magnitude −3.8 in the morning sky. From the beginning of July through the middle of August it rises out of the east-northeast sky just as dawn breaks. In August it passes a couple of degrees above Mercury on the mornings of the 9th and 10th. In the second half of August it loses altitude noticeably as it begins its plunge back toward the Sun. A narrowing crescent Moon slides past Venus on the mornings of the 21st and 22nd. By the end of August Venus is rising a bit more than an hour before the Sun.

Mars starts July setting a little more than two hours after the Sun. But the planet is shining at only magnitude +1.8—as dim as it can get. Look for it low in the west-northwest sky, beginning about an hour after sunset. Don't confuse it with Saturn, which is about three times brighter, but well below and to the right of Mars. If you are blessed with very clear weather on the evenings of the 21st and 22nd, look for Mars hovering less than a degree above and to the right of Regulus, the brightest star in the constellation Leo, the lion. You'll probably need binoculars to pick them up, but if you do, you'll likely be impressed by the color contrast between yellow-orange Mars and bluish Regulus.

This summer Jupiter is the most favorably placed planet to view. At the start of July it's shining brightly at magnitude −2.3 in the south-southwest sky and doesn't set until around 2 A.M. local daylight time. At the start of August it's in the southwest at sunset and sets around midnight. By the end of August it's setting about two and a half hours after sunset. Jupiter's retrograde, or westward, motion among the stars ends on July 6; thereafter, it starts shifting back to the east and will approach the star Zubenelgenubi, also known as Alpha Librae in the constellation Libra, the scales, for the rest of July and August. By August 1, the star and the planet are within five degrees of each other, but the two bodies continue closing in to a separation of less than two degrees by month's end. Look for Jupiter at dusk on the 29th, hovering above and to the right of a fat crescent Moon.

Saturn, for the first couple of weeks of July, can be spied low in the west-northwest sky for about an hour after sunset. Ultimately, however, the planet disappears into the glow of evening twilight. Use Mercury and brilliant Venus to guide you to Saturn as it emerges into the morning sky in late August. On the 20th, Saturn approaches to within slightly more than one degree of Mercury; both planets lie below and to the left of Venus. A sliver of a crescent Moon passes well above and to the left of Saturn on the morning of the 22nd. The next morning, Mercury and Venus form the end points of a diagonal line about eight degrees long against the sky, while Saturn lies almost exactly halfway in between. By the 26th, Saturn lies a half degree below and slightly to the left of Venus. By the following morning it is a half degree above and slightly to the right of Venus. But compared with that dazzling morning "star," Saturn appears only a forty-eighth as bright.

The Moon in July waxes to first quarter on the 3rd at 12:37 P.M., and becomes full on the 10th at 11:02 P.M. It wanes to last quarter on the 17th at 3:12 P.M. and to new on the 25th at 12:31 A.M. On the 20th a waning crescent Moon, 24 percent illuminated, occults, or passes in front of, the Pleiades star cluster as seen from eastern North America. That early-morning event takes place about a quarter of the way up in the eastern sky. In some ways it will be the reverse of the occultation of April 1. This time, between roughly 3 and 5 A.M. eastern daylight time, stars disappear along the Moon's sunlit crescent and reappear from behind the dim earthlit edge.

In August the Moon waxes to first quarter on the 2nd at 4:46 A.M., and to full on the 9th at 6:54 A.M. The Moon wanes to last quarter on the 15th at 9:51 P.M., and returns to new on the 23rd at 3:10 P.M. The Moon then comes back to first quarter for the second time in August on the 31st at 6:56 P.M.

Earth reaches aphelion, its farthest point from the Sun, on July 3 at 7 P.M.; the two bodies will be 94,507,915 miles apart.

The Perseids are one of the most active and reliable meteor displays of the year. Unfortunately, the bright light of a waning gibbous Moon—four days past full—will largely spoil this year's Perseid show. The show peaks on the morning of August 13. You might want to watch anyway, because even in the brightest moonlight a brilliant Perseid fireball occasionally blazes across the sky. The best time to watch is between midnight and dawn. Lie down and gaze at the part of the sky directly away from the Moon.

*Unless otherwise noted, all times are given in eastern daylight time.*

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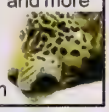

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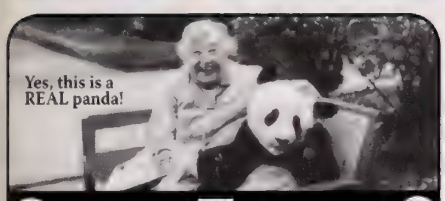
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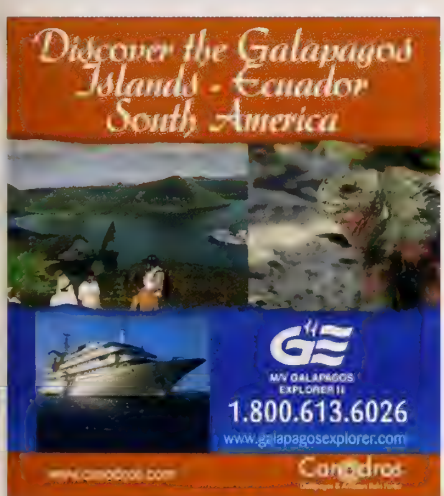
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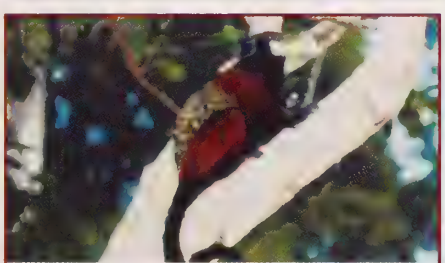
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# *Yellowstone to Yukon*

## Opens July 15, 2006

*Yellowstone to Yukon*, an enthralling exhibition of over 40 full-color photographs, opens July 15, 2006, in the American Museum of Natural History's IMAX Corridor on the first floor. On view through January 15, 2007, the exhibition showcases the diverse flora, fauna, and geology of the North American West—from Wyoming to the Yukon Territory—with lush images of breathtaking landscapes and spectacular wildlife. These photographs take viewers on an unrestricted journey through the wilderness as well as the rapidly developing areas of the Yellowstone to Yukon region to explore an ambitious corridor initiative that connects habitats so wide-ranging animals can travel unimpeded by human structures and development.

WAYNE SAWCHUK

Moose in burnt boreal forest

The photographs on display illustrate some challenges and current solutions for reconciling human and economic development with wildlife conservation. The exhibition depicts, for example, wild animals crossing roadways, which is hazardous to both the animals and drivers. Juxtaposed against these scenes of humans' interaction with the wild are images of animals using "wildlife overpasses" constructed for the animals' safe passage, demonstrating marked headway in conservation efforts in the region.

Eleanor Sterling, Director of the Museum's Center for Biodiversity and Conservation, curates the installation of *Yellowstone to Yukon* at the Museum.

JOEL BERGER

Herd of pronghorn antelope

Some of the photographs in this exhibition are taken from the book *Yellowstone to Yukon: Freedom to Roam*, which is available in the Museum Shop.

This exhibition was developed by the American Museum of Natural History's Center for Biodiversity and Conservation in concert with the Yellowstone to Yukon Conservation Initiative and the Wilburforce Foundation and is made possible by their support. Additional generous support provided by the Woodcock Foundation.

# *LIZARDS & SNAKES: ALIVE!*

## July 1, 2006–January 7, 2007

D. FINNIN/AMNH

Veiled chameleon

This new exhibition at the American Museum of Natural History will captivate children and adults alike with more than 60 live lizards and snakes. Visitors will learn how lizards and snakes are part of the same group of animals; about the way these diverse creatures move, from leaping to slithering to running on water; the way they capture food, from "snaking" out their projectile tongues to unhinging their gaping jaws; their effective methods of camouflage; and other sometimes surprising adaptations.

## PEOPLE AT THE AMNH

**Michael Cosaboom**
Manager of Interactive Exhibits
Department of Exhibitions

D. FINNIN/AMNH

Michael Cosaboom, whose team develops computer-based media for special exhibitions, says that of all the projects he's worked on in his nearly five years at the Museum, the new exhibition *Lizards & Snakes: Alive!* is his favorite.

"This is the first show where I've been involved from start to finish on not just the technical side but content as well. The curators have been amazing, giving really specific feedback about what they want."

Michael and his team collaborated with the curators to create an interactive, educational video game of a snake on the hunt that ends with a high-definition depiction of the snake's skull while it swallows its prey.

"People will see a desert environment from the point of view of a snake, see how it moves when it strikes, and what happens when it swallows something. We were able to produce this with scientific accuracy—and it's fun."

After studying anthropology at the University of Michigan, the Wilmington, Delaware, native spent several years doing social work and youth work when he got "excited by how young people reacted to computers." He went on to hone his skills in computer programming and design at NYU's Interactive Telecommunications Program.

Off the job, Michael spends as much time as he can with his five-year-old son, Wilder, who is as excited about his father's workplace as Michael is. "Wilder loves coming to the Museum. In his imagination, he has his own museum that he runs."

# Last Chance! *DARWIN*

### Closes August 20

D. FINNIN/AMNH

Galápagos tortoise

This tortoise is just one of the live animals in *Darwin* that has made the exhibition so popular that it was extended three months past its original closing date. But now your last chance to see this stunning exhibition is approaching: *Darwin* closes August 20. Don't miss live animals, original manuscripts, specimens collected by the great naturalist himself, a meticulous re-creation of his study, and much more.

## STARRY NIGHTS *Live Jazz*

ROSE CENTER FOR EARTH AND SPACE

***Friday, June 2***
*6:00 and 7:30 p.m.*

Jeremy Pelt & Creation

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***Friday, August 4***
*6:00 and 7:30 p.m.*

Visit www.amnh.org for lineup.

The 7:30 p.m. set will be broadcast live on WBGO Jazz 88.3 FM.

*Starry Nights* is made possible, in part, by Fidelity Investments.

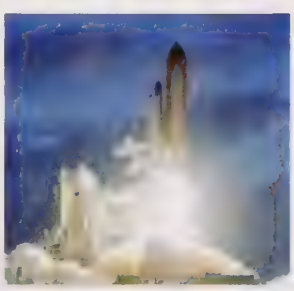
R. MACHINS/AMNH

Starry Nights, the enormously popular series of live jazz performances under the sphere of the Hayden Planetarium, takes place on the first Friday of every month. The series features renowned jazz musicians performing in one of the most spectacular settings in New York. Visitors to Starry Nights can enjoy mouthwatering tapas along with wine and other beverages during performances.

# Space Shuttle Launch LIVE

### Visit AMNH Space Events Web page for details

July marks the return of NASA's Space Shuttle fleet to service after more than three years of engineering analysis and redesign. Join scientists and space educators from AMNH to watch the launch of Space Shuttle *Discovery* live in the Cullman Hall of the Universe in the Rose Center for Earth and Space. Launch is currently scheduled for no earlier than July 1. Please visit www.amnh.org/space-events to get an up-to-the-minute schedule of events as the launch approaches.



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# Museum Events

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## EXHIBITIONS

### LAST CHANCE! *Darwin*

*Through August 20, 2006*

Featuring live animals, actual fossil specimens collected by Charles Darwin, and manuscripts, this magnificent exhibition offers visitors a comprehensive, engaging exploration of the life and times of Darwin, whose discoveries launched modern biological science.

The American Museum of Natural History gratefully acknowledges **The Howard Phipps Foundation** for its leadership support. Significant support for *Darwin* has also been provided by Chris and Sharon Davis, Bill and Leslie Miller, the Austin Hearst Foundation, Jack and Susan Rudin, and Rosalind P. Walter. Additional funding provided by the Carnegie Corporation of New York, Dr. Linda K. Jacobs, and the New York Community Trust–Wallace Special Projects Fund.

*Darwin* is organized by the American Museum of Natural History, New York (www.amnh.org), in collaboration with the Museum of Science, Boston; The Field Museum, Chicago; the Royal Ontario Museum, Toronto, Canada; and the Natural History Museum, London, England.

S. QUIRIN/AMNH

Blue-footed boobies

### *Lizards & Snakes: Alive!*

*Opens July 1, 2006*

Live lizards and snakes are the center of attention in this engaging exhibition that will explore these creatures' remarkable adaptations, including projectile tongues, deadly venom, amazing camouflage, and sometimes surprising modes of movement. Fossil specimens, life-size models, videos, and interactive stations will complement the more than 60 live animals representing 27 species.

*Lizards & Snakes: Alive!* is made possible, in part, by grants from The Dyson Foundation and the Amy and Larry Robbins Foundation.

*Lizards & Snakes: Alive!* is organized by the American Museum of Natural History, New York (www.amnh.org), in collaboration with the Fernbank Museum of Natural History, Atlanta, and the San Diego Natural History Museum, with appreciation to Clyde Peeling's Reptiland.

WANG TINGGUANG, WANGLIN VILLAGE. PHOTO: OICE

Ding Shunchang

### EXTENDED! *Voices from South of the Clouds*

*Through January 2, 2007*

China's Yunnan Province is revealed through the eyes of the indigenous people, who use photography to chronicle their culture, environment, and daily life.

The exhibition is made possible by a generous grant from Eastman Kodak Company. The presentation of this exhibition at the American Museum of Natural History is made possible by the generosity of the Arthur Ross Foundation.

### *Vital Variety*

*Ongoing*

Beautiful close-up photographs highlight the diversity of invertebrates.

## GLOBAL WEEKENDS

### Indigenous Peoples' Day

*Saturday, 8/12, 1:00–5:00 p.m.*

The afternoon includes Native American cultural performances, films, and a special guest from the United Nations.

Global Weekends are made possible, in part, by The Coca-Cola Company, the City of New York, and the New York City Council. Additional support has been provided by the May and Samuel Rudin Family Foundation, Inc., the Tolan Family, and the family of Frederick H. Leonhardt.

## LECTURES

### Adventures in the Global Kitchen: Rum

*Tuesday, 7/11, 7:00 p.m.*

Explore the rise, fall, and return of rum. This program includes tastings of rum-based cocktails.

### Lessons of the Gecko

*Tuesday, 7/18, 7:00 p.m.*

The millions of tiny hairs on a gecko's feet are helping scientists develop new adhesives. Discuss the implications of this research and its potential uses.

## FAMILY AND CHILDREN'S PROGRAMS

### Wild, Wild World: Lizards & Snakes

*Saturday, 7/1, 12:00 noon–1:00 p.m. and 2:00–3:00 p.m.*

Live lizards and snakes, introduced by "Lizard Man" Clyde Peeling.

*Wild, Wild World* is made possible, in part, by Mortimer B. Zuckerman.

CLYDE PEELING'S REPTILELAND

Clyde Peeling with alligator

### Free Event! How I Became a Herpetologist

*Sunday, 7/9, 12:00 noon–1:15 p.m.*

Join the co-curators of the exhibition *Lizards & Snakes: Alive!* to learn what inspired them to become scientists.

### LIZARD SUNDAYS

$25 each; $65 for all three (of the same age group)

### Lizard Locomotion

*Sunday, 7/16, 11:00 a.m.–12:30 p.m. (Ages 4–6, each child with one adult) and 1:30–3:00 p.m. (Ages 7–9)*

KELLAR AUTUMN

Gecko adhering to glass

### Lizards Who Lunch

*Sunday, 7/23, 11:00 a.m.–12:30 p.m. (Ages 4–6, each child with one adult) and 1:30–3:00 p.m. (Ages 7–9)*

### Lizard Lore

*Sunday, 7/30, 11:00 a.m.–12:30 p.m. (Ages 4–6, each child with one adult) and 1:30–3:00 p.m. (Ages 7–9)*

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For details, visit www.amnh.org or call 212-769-5758.

## HAYDEN PLANETARIUM PROGRAMS

TUESDAYS IN THE DOME

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*Tuesday, 7/4, 6:30–7:30 p.m.*

**The Grand Tour**
*Tuesday, 8/1, 6:30–7:30 p.m.*

***This Just In...***

**July's Hot Topics**
*Tuesday, 7/18, 6:30–7:30 p.m.*

**August's Hot Topics**
*Tuesday, 8/15, 6:30–7:30 p.m.*

***Celestial Highlights***

**Midsummer Skies**
*Tuesday, 7/25, 6:30–7:30 p.m.*

**The Triangle and the Celestial Sea**
*Tuesday, 8/29, 6:30–7:30 p.m.*

T. GOELMAN/AMNH

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*Cosmic Collisions* was developed in collaboration with the Denver Museum of Nature & Science; GOTO, Inc., Tokyo, Japan; and the Shanghai Science and Technology Museum. Made possible through the generous support of CIT. *Cosmic Collisions* was created by the American Museum of Natural History with the major support and partnership of the National Aeronautics and Space Administration's Science Mission Directorate, Heliophysics Division.

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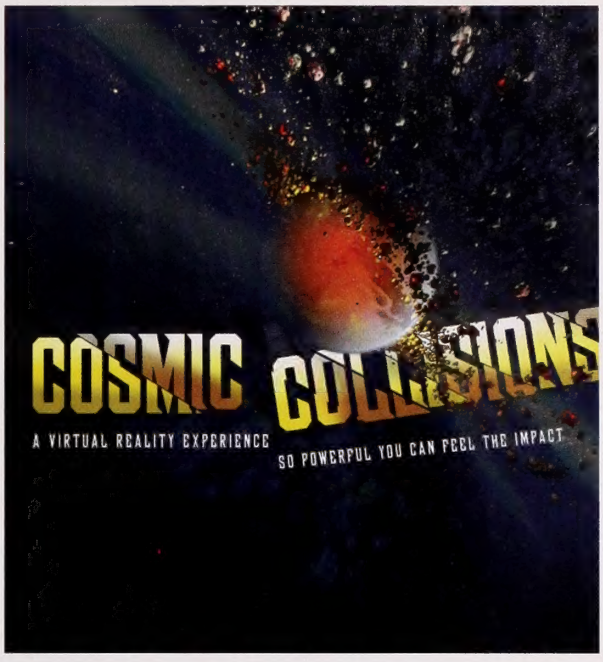


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# Hard Labor at Bear Gulch

By Eugene H. Kaplan

Grumpy, fuzzy, scholarly type was beside himself. Halfway up the ten-foot-high rock wall he'd run out of toeholds, and he clung desperately to the tiny fingerholds above him. The wall was made of layers of shale, inch-thick ledges protruding irregularly from the mesa, and he couldn't find a higher one to stand on. The distinguished professor of physiology and evolution was stuck.

I pushed on his bottom. Someone pulled him from above. Finally he scrabbled onto the top of the mesa and fell, prostrate, on the flat, hard, dusty surface. After a minute he rolled over, tears of exertion still in his eyes.

About ten people toiled atop the mesa, all paleontologists. We were prospecting for fossils at one of those small, scarcely known paleontological sites that abound in the western United States. This one—Bear Gulch—is situated on a cattle ranch in central Montana. The leader of our team had written profusely about shark fossils of the Mississippian period, 300 million years ago. Back then, Bear Gulch was an inlet of what was to become the Pacific Ocean. Warm and shallow, it was a perfect pupping ground for sharks. Occasionally a juvenile shark would die there and sink to the seafloor, soon to be buried in the soft, oxygen-poor bottom mud.

*Layers of petrified sediment in Bear Gulch, Montana (above), hold some of the best-preserved marine fossils in the world, including this 300-million-year-old horseshoe crab (left).*

Those rich, shallow waters teemed with plankton. They, too, sank to the bottom when they died, forming a layer on top of the mud. Bacteria dined on them, oxidizing the protoplasm of the dead plankton layer. Reproducing every twenty minutes, the bacterial masses used up virtually every molecule of available oxygen. In this oxygen-starved burial place, the shark carcasses remained intact until the mud, gradually and under immense pressure, became stone—shale. Along with their encasement of mud, the tiny sharks turned to stone. Three hundred million years later, a team of toiling paleontologists broke into their tombs and let the sunshine in.

The graduate students punctuated their jolly conversations with grunts of exertion as they pried up layers of the petrified mud. The technique was to slip the sharp end of a five-foot steel spike into the junction between two layers and pound at the seam until the layers loosened. Then they would wedge the spike into the shale and lever it upward, breaking off a slab a yard or so wide. When the slab was turned over, it would usually reveal . . . nothing. But occasionally a more professional-sounding grunt drew everyone's attention to a digger who had found, in all its perfection, the imprint of a tiny shark, its scales defined and its eyes turned upward in a stony stare.

My fuzzy, distinguished colleague and I also grunted frequently while we worked—not to prove we were just as professional as the grad students, but because our aging bodies made it hard to lift the heavy layers of rock. Sweating under a glaring sun, we finally learned how to use mechanical advantage, wedging up pieces of shale with the best of them. Nevertheless, the flat undersides of slab after laborious slab had nothing to show us.

Finally the two of us came upon a curled object—shaped like a sinuous peanut—embedded in the shale. Excited, we dragged the two-foot-wide chunk of rock to the head honcho, who stared at it intently and informed us it was a coprolite. We looked at him quizzically. "It's petrified fish feces," he explained. All that labor and exhaustion only to find ancient fish poop!

The team worked until dark, our labors illuminated by a magnificent, luminous sunset. After dinner that evening the buttes and mesas rang with laughter as we were presented with our hard-won trophy—the coprolite—which, to this day, lies in state in the glass-fronted case that doubles as my class museum. Thoroughly tired, and mildly amused by our moment of triumph, I crawled into my tent, pushing at its nylon floor to carve out a flat space amid the ubiquitous cow flops. A pat of "prairie pancake" was my pillow.

The next day, another grunt brought us running. Although the fossil turned out to be of little interest to this group of ancient-shark specialists, to me it was a real treasure. I let loose a holler. There on the underside of the rock was a small, perfect, 300-million-year-old replica of a modern-day horseshoe crab.

*Eugene H. Kaplan is Axinn Distinguished Professor of Conservation and Ecology at Hofstra University, in Hempstead, New York. This story is adapted from his book* Sensuous Seas: Tales of a Marine Biologist, *which will be published in August by Princeton University Press.*

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